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SPACE SHUTTLE

Solid Rocket Motors
Thiokol Corporation

Flight Motor Set 360L007 (STS-33R) Final Report

June 1990

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National Aeronautics and Space Administration
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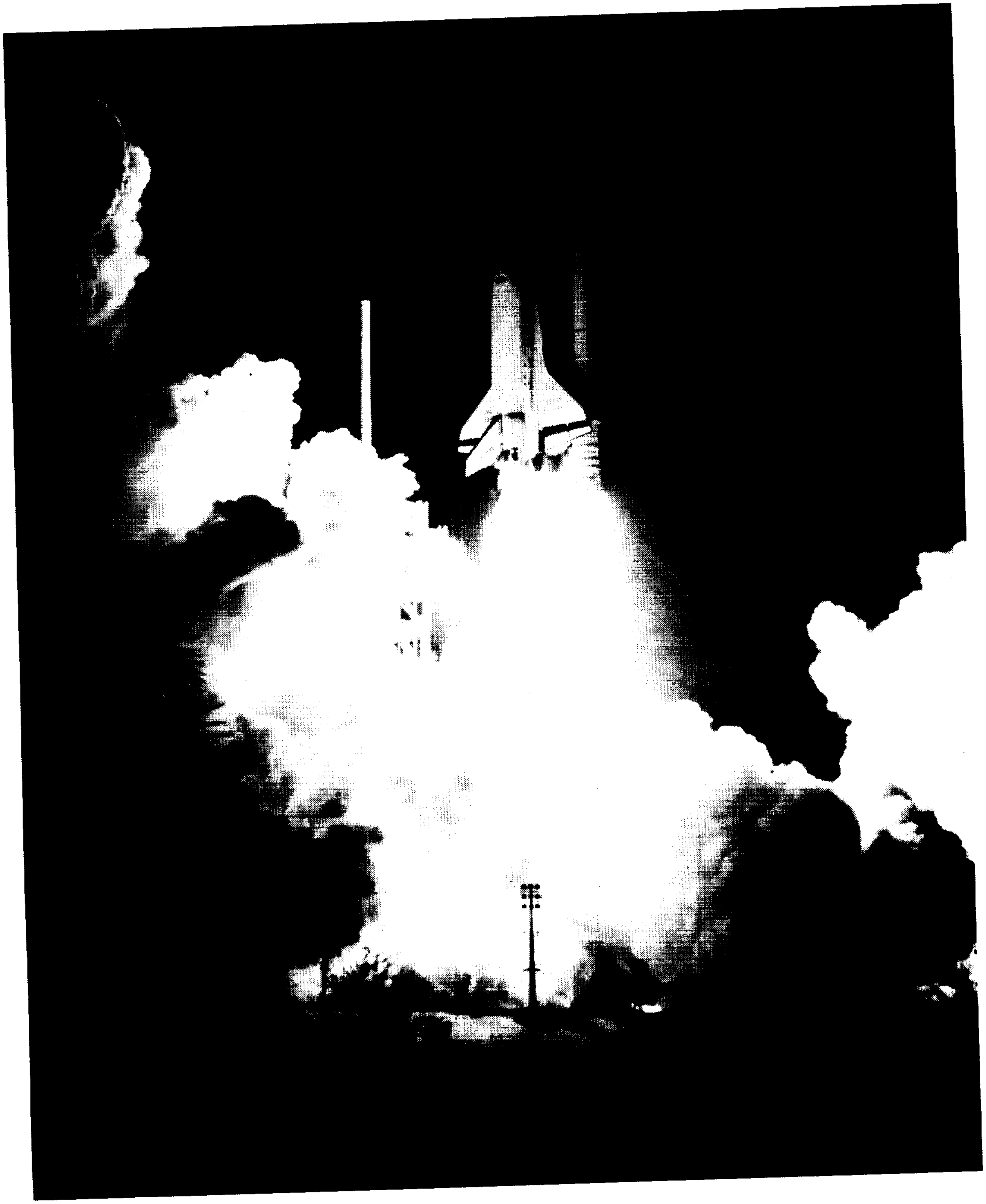

STS-33R (Discovery), carrying a DoD payload, was successfully launched at 6:23 p.m. CST, 22 Nov 1989

Thiokol CORPORATION
SPACE OPERATIONS

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Flight Motor Set 360L007 (STS-33R)
Final Report

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ABSTRACT

Flight motor set 360L007 was launched at approximately 6:23 p.m. central standard time (89:327:00:23:30.000 Greenwich mean time) on 22 Nov 1989 as part of NASA space shuttle mission STS-33R. As with all previous redesigned solid rocket motor launches, overall motor performance was excellent. There were no debris concerns for either motor. Both motors exhibited unbonds on one factory joint weatherseal.

All ballistics contract end item specification parameters were verified, with the exception of ignition interval and rise rates. Ignition interval and rise rates could not be verified due to the elimination of developmental flight instrumentation from fourth flight and subsequent, but the low sample rate data that were available showed nominal propulsion performance. All ballistic and mass property parameters closely matched the predicted values and were well within the required contract end item specification levels that could be assessed.

All 108 GEI measurements performed properly throughout the prelaunch phase. Evaluation of the ground environment instrumentation measurements again verified thermal model analysis data and showed agreement with predicted environmental effects. No launch commit criteria thermal violations occurred. All joint heaters operated normally, but a high voltage reading was noted on the left hand aft heater, which was immediately determined to be a voltage sensor error and not a heater anomaly due to no current increase. See Section 4.10.2 for details.

Postflight inspection again verified superior performance of the insulation, phenolics, metal parts, and seals. The igniter seals, which were replaced preflight due to subsurface seal void concerns, showed no anomalous conditions. Postflight evaluation indicated both nozzles performed as expected during flight. All combustion gas was contained by insulation in the field and case-to-nozzle joints.

Recommendations were made concerning improved thermal modeling and measurements. The rationale for these recommendations and detailed results are contained in this report.

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ACRONYMS AND ABBREVIATIONS

CCP	carbon-cloth phenolic
CDS	Central Databasing Service
CEI	contract end item
cg	center of gravity
EPDM	ethylene-propylene-diene monomer
ET	external tank
FBMBT	flex bearing mean bulk temperature
FEWG	Flight Evaluation Working Group
FMEA	failure modes and effects analysis
FSEC	Florida Solar Energy Center
GCP	glass-cloth phenolic
GEI	ground environment instrumentation
HOSC	Huntsville Operations Support Center
HPM	high-performance motor
IFA	in-flight anomaly
IPR	interim problem report
IR	infrared
IVBC	integrated vehicle baseline configuration
JPS	joint protection system
KSC	Kennedy Space Center
LCC	launch commit criteria
LRU	line replaceable unit
LSC	linear shaped charge
MSFC	Marshall Space Flight Center
MSID	measurement stimulation identification number
NSI	NASA standard initiator
NSTS	National Space and Transportation System
OBR	outer boot ring
OD	outside diameter
OFI	operational flight instrumentation
OPT	operational pressure transducer
PMBT	propellant mean bulk temperature
RSRM	redesigned solid rocket motor
RSRML	lightweight redesigned shuttle solid rocket motor
RTD	resistance temperature detector
RTV	room temperature vulcanizing (rubber)
S&A	safety and arming device
sec	second
SF	safety factor
SSI	shuttle standard initiator
sps	samples per second
SRB	solid rocket booster
SRM	solid rocket motor
SSME	space shuttle main engine
STI	shuttle thermal imager
3-D	three dimensional
TPS	thermal protection system
TVC	thrust vector control
USBI	United Space Boosters, Inc.
VAB	vehicle assembly building

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INTRODUCTION

Solid rocket booster (SRB) ignition command for flight motor set 360L007 was given at 89:327:00:23:30.000 GMT (approximately 6:23 p.m. CST) on 22 Nov 1989 at Kennedy Space Center (KSC), Florida. This flight was the 32nd space shuttle mission (mission designation STS-33R) and the seventh redesigned solid rocket motor (RSRM) flight. The individual motor identification numbers were 360L007A (left-hand (LH)) and 360L007B (right-hand (RH)), indicating that both cases were lightweight. Additional case configuration details are addressed in Section 4.2.

This volume (Volume I) of this report contains the Thiokol Flight Evaluation Working Group (FEWG) inputs submitted to United Space Boosters, Inc. (USBI) for incorporation into the shuttle prime contractors' FEWG report (Document MSFC-RPT-1579). An executive summary of the entire RSRM flight set performance and a one-to-one correlation of conclusions by objectives (and contract end item (CEI) paragraphs) are also included in this report. The detailed component volumes of this report (and the approximate timeline for volume release from the launch date) are listed in Table 1-1. TWR-60063 is a flow report that starts with receipt of hardware at KSC. It documents aft booster buildup and RSRM stacking, including processing milestones and highlights, stacking configuration, and significant discrepancy reports, problem reports, etc.

The subsections of this report volume that were submitted to USBI as part of the FEWG report are so designated with the FEWG report paragraph number.

Table 1-1. Component Volume Release Schedule

Volume	Description/ Component	Interim Release	Final Release
I	Systems overview	NA	Approximately 60 days after launch
II	Case/seals	NA	60 days after washout of last segment at H-7 (Clearfield, Utah)
III	Internal insulation	60 days after last joint demate at KSC	60 days after washout of last segment at H-7
IV	TPS/JPS/heaters/systems tunnel	NA	60 days after hydrolase is complete at KSC
V	Nozzle	NA	60 days after nozzle phenolic sectioning is complete
VI	Igniter	NA	60 days after washout of last igniter chamber at H-7
VII	Performance/ mass properties	NA	60 days after launch

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OBJECTIVES

Flight objectives for the seventh Thiokol RSRM flight set were intended to satisfy the requirements of CPW1-3600A as listed in parenthesis below. A one-to-one correlation of conclusions by objectives (and CEI paragraphs) is included in Section 3.2 of this report.

Qualification Objectives

A. The ignition interval shall be between 202 and 262 ms with a 40 ms environmental delay after ignition command to the solid rocket motor (SRM) shuttle standard initiators (SSI) in the safe and arm device (S&A) up to a point at which the headend chamber pressure has built up to 563.5 psia (3.2.1.1.1.1).

B. The maximum rate of pressure buildup shall be 115.9 psi for any 10-ms interval (3.2.1.1.1.2).

C. Verify that the thrust-time performance falls within the requirements of the nominal thrust-time curve (3.2.1.1.2.1, Table I).

D. Certify that the measured motor performance parameters, when corrected to a 60°F propellant mean bulk temperature (PMBT), fall within the nominal value, tolerance, and limits for individual flight motors (3.2.1.1.2.2, Table II).

E. With a maximum PMBT difference of 1.4°F between the two RSRMs on a shuttle vehicle, the differential thrust between the two RSRMs shall not be greater than the values given in Table III at any time during the periods shown. These differentials are applicable over the PMBT range of +40° to +90°F (3.2.1.1.2.3).

F. Certify that the thrust-time curve complies with impulse requirements (3.2.1.1.2.4).

G. Certify that specified temperatures are maintained in the case-to-nozzle joint region during the countdown launch commit criteria (LCC) time period (3.2.1.2.1.f).

H. The case segment mating joints shall contain a pin retention device (3.2.1.3.g).

I. Certify the performance of the igniter heater so it maintains the igniter gasket rubber seals between 64° and 130°F (3.2.1.5.3).

J. Verify that the S&As perform as required, using the specified power supply (3.2.1.6.1.2).

K. Verify that the operational flight instrumentation (OFI) is capable of launch readiness checkout after the ground system has been connected on the launch pad (3.2.1.6.2).

L. Certify the proper operation of the operational pressure transducer (OPT) during flight (3.2.1.6.2.1).

M. The ground environment instrumentation (GEI) shall monitor the temperature of the SRBs while on the ground at the pad. It is not required to function during flight. These instruments will be monitored on the ground through cables with lift-off breakaway connectors (3.2.1.6.2.3).

N. When exposed to the thermal environments of 3.2.7.2, the systems tunnel floorplates and cables will be maintained at a temperature at or below that specified in ICD 3-44002 (3.2.1.10.1).

O. Certify the performance of the field joint heater and sensor assembly so that it maintains the case field joint at 75°F minimum. Field joints shall not exceed 130°F (3.2.1.11.a).

P. Certify that each field joint heater assembly meets all performance requirements (3.2.1.11.1.2).

Q. Demonstrate isolation of subsystem anomalies if required on seventh flight (360L007) hardware (3.2.3.3).

R. Demonstrate the RSRM capability of vertical disassembly if required (3.2.5.1).

S. The RSRM and its components will be adequately protected, by passive means, against natural environments during transportation and handling (3.2.8.c).

T. Demonstrate the remove and replacement capability of the functional line replaceable unit (LRU) (3.4.1).

<u>Objectives by Inspection</u>

A. Inspect all RSRM seals for performance (3.2.1.2).

B. Inspect the seals for satisfactory operation within the specified temperature range that results from natural and induced environments (3.2.1.2.1.b).

C. Inspect the factory joint insulation for accommodation of structural deflections and erosion (3.2.1.2.2.a).

D. Inspect the factory joint insulation for operation within the specified temperature range (3.2.1.2.2.b).

E. Verify that at least one virgin ply of insulation exists over the factory joint at the end of motor operation (3.2.1.2.2.d).

F. Verify that no leakage occurred through the insulation (3.2.1.2.2.e).

G. Verify that the flex bearing seals operate within the specified temperature range (3.2.1.2.3.b).

H. Verify that the flex bearing maintained a positive gas seal between its internal components (3.2.1.2.3.d).

I. Verify that the ignition system seals operate within the specified temperature range (3.2.1.2.4.b).

J. Verify that the nozzle internal seals and exit cone field joint seals operate within the specified temperature range (3.2.1.2.5.b).

K. Inspect the risers for damage or cracks that would degrade the pressure holding capability of the case (3.2.1.3.c).

L. Inspect the flex bearing for damage due to water impact (3.2.1.4.6).

M. Verify that the environmental protection plug will withstand space shuttle main engine (SSME) shutdown, if incurred (3.2.1.4.7.b).

N. Verify the performance of the nozzle liner (3.2.1.4.13).

O. Inspect the ignition system seals for evidence of hot gas leakage (3.2.1.5.a).

P. Inspect the igniter for evidence of debris formation or damage (3.2.1.5.2).

Q. Inspect the seals for visible degradation from motor combustion gas (3.2.1.8.1.1.d).

R. Verify by inspection that the insulation met all performance requirements (3.2.1.8.1.1.e).

S. Inspect insulation material for shedding of fibrous or particulate matter (3.2.1.8.1.1.f).

T. Inspect the joint insulation for evidence of slag accumulation (3.2.1.8.1.1.g).

U. Inspect the thermal protection system (TPS) to insure that there was no environmental damage to the RSRM components (3.2.1.8.2).

V. Inspect for thermal damage to the igniter chamber and the adapter metal parts (3.2.1.8.3).

W. Verify that the case components are reusable (3.2.1.9.a).

X. Verify that the nozzle metal parts are reusable (3.2.1.9.b).

Y. Verify through flight demonstration and a postflight inspection that the flex bearing is reusable (3.2.1.9.c).

Z. Verify that the igniter components are reusable (3.2.1.9.d).

AA. Verify by inspection that the S&A is reusable (3.2.1.9.e).

AB. Verify by inspection that the OPTs are reusable (3.2.1.9.f).

AC. Inspect the case factory joint external seal for moisture (3.2.1.12).

AD. Inspect the hardware for damage or anomalies as identified by the failure modes and effects analyses (FMEA) (3.2.3).

AE. Determine the adequacy of the design safety factors (SF), relief provisions, fracture control, and safe life and/or fail-safe characteristics (3.2.3.1).

AF. Determine the adequacy of subsystem redundancy and fail-safe requirements (3.2.3.2).

AG. Inspect the identification numbers of each reusable RSRM part and material for traceability (3.3.1.5).

AH. Verify the structural SF of the case/insulation bond (3.3.6.1.1.2.a).

AI. Verify by inspection the remaining insulation thickness of the case insulation (3.3.6.1.2.2, 3.3.6.1.2.3, 3.3.6.1.2.4, 3.3.6.1.2.6).

AJ. Verify by inspection the remaining nozzle ablative thicknesses (3.3.6.1.2.7).

AK. Verify the nozzle SFs (3.3.6.1.2.8).

AL. Inspect metal parts for presence of stress corrosion (3.3.8.2.b).

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RESULTS SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

3.1 RESULTS SUMMARY

This section contains an executive summary of the key results from the flight data evaluation and postflight inspection. Additional information and details can be found in the referenced report sections or in the separate component volumes of this report.

3.1.1 In-Flight Anomalies

There were no in-flight anomalies (IFA) relating to RSRM motor set 360L007.

3.1.2 Mass Properties

All SRM weight values were well within the CEI specification limits, as has been the case on all previous RSRM motor sets. Complete mass property values are included in Section 4.3 of this volume and Volume VII of this report.

3.1.3 Propulsion Performance (ballistics)

3.1.3.1 Propellant Burn Rates/Specific Impulse. The delivered burn rate (at 71°F and 625 psia) for flight motor set 360L007 was 0.368 ips for the LH motor, which matched the prediction, and 0.369 ips for the RH motor (0.001 ips higher than predicted). The reconstructed vacuum specific impulse values were 268.2 lbf*sec/lbm for the LH motor and 267.6 lbf*sec/lbm for the RH motor at 71°F, which was within 0.3 percent of the predicted value of 268.5 lbf*sec/lbm.

3.1.3.2 CEI Specification Values. All impulse values, time parameters, and pressure thrust levels (all corrected to 60°F) again showed excellent agreement with the motor nominal performance requirements. Actual value variations from the allowable CEI specification limits were all within 2 percent, significantly less than the allowable 3-sigma variation. Thrust imbalance was also well within the specification limits for the required time periods.

Due to the elimination of DFI after STS-29R (360L003), no high sample rate pressure data were available. Therefore, the CEI specification requirement to verify ignition interval, pressure rise rate, and ignition time thrust imbalance could not be addressed. A complete evaluation of all ballistic parameters is included in Section 4.4 of this volume.

3.1.4 S&A Device

The S&A safe-to-arm rotation times were all within the minimum 2-sec requirement during the actual launch, although there was some concern that the S&As might perform more slowly than expected when a delayed rotation time of 2.6 sec was revealed during prelaunch functionality testing. An interim problem report (IPR) (No. 33RV-0165) was written, and to close it an additional S&A functionality test was performed. S&A times are in Section 4.10.4.

3.1.5 Ascent Loads and Structural Dynamics

Due to elimination of DFI after STS-29R (360L003), no evaluation of the RSRM loading or vibration characteristics is possible.

3.1.6 External TPS/Joint Heater Evaluation

Postflight assessment results stated all TPS components to be in very good to excellent condition, with typical flight heat effects and erosion. National Space and Transportation System (NSTS) debris criteria for all missing TPS were not violated. Retrieval and towback were delayed 24 hr by high sea states.

All six field joint heaters performed adequately and as expected throughout the required operating periods, but a high voltage reading was noted on the LH aft heater. The high voltage was not accompanied by a current increase, so it was determined that the high reading was a sensor anomaly. See Section 4.10.2 for details. Prior to launch, a launch commit criteria (LCC) contingency was created to lower the minimum redline temperature at any field joint from 85° to 69°F in the event of primary and secondary heater failure. A detailed TPS and heater evaluation is in Section 4.8 of this volume.

3.1.7 Aero/Thermal Evaluation

3.1.7.1 On-Pad Local Environments/Thermal Model Verification. The on-pad local environments were lower than November conditions (62° to 73°F), with ambient temperatures ranging from 50° to 76°F. Windspeeds were lower than the historical conditions. Wind direction oscillated from east to south during the LCC timeframe.

No extreme outward cooling effects from external tank (ET) cryogenic loading were noted.

3.1.7.2 LCC/Infrared (IR) Readings. No LCC thermal violations were noted; all field and igniter joint heaters performed adequately. The aft skirt purge was activated approximately 15.5 hr prior to launch. The LH case-to-nozzle joint temperature was at the minimum LCC limit of 75°F at the beginning of the LCC window due to the delayed aft skirt purge start.

IR measurements taken by the IR gun during the T-3 hr ice/debris pad inspection were not consistent with GEI and shuttle thermal imager (STI) readings. Due to this inconsistency, which has been noted during previous countdowns, the data were not used or recorded by the ice team. The STI temperature measurements were used along with GEI measurements to monitor SRM surface temperatures.

No ascent and reentry thermal evaluation of the aft skirt area (as was done on RSRM Flights 1 through 3) was possible due to DFI elimination. A complete aero/thermal evaluation is in Section 4.8 of this volume.

3.1.8 Instrumentation

All 108 GEI measurements performed properly throughout the prelaunch phase. All GEI are disconnected by breakaway umbilicals at SRB ignition and are not operative during flight. All OPTs functioned properly during flight and successfully passed the prelaunch calibration checks. A complete discussion of GEI and all instrumentation is in Section 4.10 of this volume.

3.1.9 Postflight Hardware Assessment

3.1.9.1 Insulation. Postflight evaluation again verified excellent insulation performance, showing that the insulation effectively contained the motor combustion gas in the two case-to-nozzle joints and six field joints. Two of the 14 weatherseals on this flight set were unbonded. No gas paths through the case-to-nozzle joint polysulfide adhesive or any other anomalous joint conditions were identified. The internal insulation in all six of the case field joints also performed as designed, with no anomalous conditions. There were no recordable clevis edge separations (over 0.1 in.). No evidence of hot gas penetration through any of the acreage insulation was found, and no severe erosion patterns were identified. A complete insulation performance evaluation is in Section 4.11.1 of this volume and Volume III of this report.

3.1.9.2 Case. The case field joint surface conditions were as expected. Field joint fretting on this flight ranged from none on one joint to locally medium on two joints. The RH center field joint had no fretting. The LH center and RH forward joints had the worst fretting. No further damage was noted on the previously fretted hardware flown.

Complete case evaluation results are in Section 4.11.2 of this volume and Volume II of this report.

3.1.9.3 Seals. The RH and LH inner and outer igniter gaskets were replaced preflight because of concerns about subsurface defects in the gasket elastomer seal. After this changeout, the RH igniter was again removed because the putty layup used was similar to procedures used on 360L006 (STS-34) igniter changeouts. (360L006 putty layup was suspect because putty was observed in the seal area of the outer gasket during disassembly.) The outer gasket was inspected for putty contamination in the seal area. The LH igniter putty was not suspect because it was held to the new, tighter dimension requirements. Putty was observed on the LH inner gasket (inner edge) from 20 to 65 deg.

All internal seals performed well, with no heat effects, erosion, or hot gas leakage evident. No motor pressure reached the field or case-to-nozzle joint seals. There was no putty on the forward or aft faces of the igniter gaskets. A complete evaluation of seals performance is in Section 4.11.3 of this volume and Volume II of this report.

3.1.9.4 Nozzle/Thrust Vector Control (TVC) Performance. Postflight evaluation indicated both nozzles performed as expected during flight, with typical smooth and uniform erosion profiles. A complete evaluation is in Section 4.11.4 of this volume and Volume V of this report.

3.2 CONCLUSIONS

Listed below are the conclusions as they relate specifically to the objectives and the CEI paragraphs. Also included with the conclusion is the section from this report (in parenthesis) where additional information can be found.

Objective	CEI Paragraph	Conclusions
Certify that the thrust-time performance falls within the requirements of the nominal thrust-time curve.	3.2.1.1.2.1 (see nominal thrust-time curve)	*Certified*. The thrust-time performance was within the nominal thrust-time curve (Figure 4.4-1).

Certify that the measured motor performance parameters, when corrected to a 60°F PMBT, fall within the nominal value, tolerance and limits for individual flight motors.	3.2.1.1.2.2 The delivered performance values for each individual motor when corrected to a 60°F PMBT shall not exceed the limits specified...	*Partially Certified.* All measurable motor performance values were well within the specification requirements (Tables 4.4-2 and 4.4-3). The ignition interval and rise rates could not be measured due to DFI elimination.
Certify that the thrust-time curve complies with impulse requirements.	3.2.1.1.2.4-- Impulse Gates Time (sec) / Total Impulse (10E6 lb-sec) 20 — 63.1 Minimum 60 — 172.9 -1, +3% Action time (AT): 293.8 minimum	*Certified.* The nominal thrust-time curve values are listed below. Time (sec) / Value LH / RH 20 — 64.78 — 65.18 60 — 173.11 — 173.36 AT — 296.75 — 296.04 (Table 4.4-1)
Certify that specified temperatures are maintained in the case-to-nozzle joint region during the countdown LCC time period.	3.2.1.2.1.f Case-to-nozzle joint O-rings shall be maintained within the temperature range as specified in ICD 2-0A002 (75° to 115°F).	*Certified.* Temperature ranges in the case-to-nozzle joint region are listed below. RH 78° - 85°F LH 75° - 83°F (due to later aft skirt purge) (Table 4.8-4)
Certify that the ignition interval is between 202 and 262 ms with a 40 ms environmental delay after ignition command.	3.2.1.1.1.1 The ignition interval shall be between 202 and 262 ms with a 40 ms environmental delay after ignition command to the SSI in the S&A up to a point at which the headend chamber pressure has built up to 563.5 psia.	*Unable to certify* due to DFI elimination (high sample rate pressure transducers).
Certify that the pressure rise rate meets specification requirements.	3.2.1.1.1.2 The maximum rate of pressure buildup shall be 115.9 psi for any 10 ms interval.	*Unable to certify* due to DFI elimination (high sample rate pressure transducers).

Certify that the motor thrust differential meets specification requirements.	3.2.1.1.2.3 With a maximum PMBT difference of 1.4°F between the two RSRMs on a shuttle vehicle, the differential thrust between the two RSRMs shall not be greater than the values given in Table III at any time during the periods shown. These differentials are applicable over a PMBT range of +40° to +90°F.	The thrust differential values were near the nominal values experienced by previous flight SRMs (Table 4.4-2).
Certify the performance of the igniter heater so it maintains the igniter gasket rubber seals between 64° and 130°F.	3.2.1.5.3 The igniter heater shall maintain the igniter gasket rubber seals between 64° and 130°F.	*Certified.* The igniter heater maintained the igniter sensors between 74° and 96°F (RH) and 72° and 96°F (LH). Sensor temperatures between 66° and 123°F ensure O-ring temperatures of 64° to 130°F (Table 4.8-4).
Certify that the S&As perform as required using the specified power supply.	3.2.1.6.1.2--Power Supply. The S&A shall meet all performance requirements....in accordance with ICD 3-44005.	*Certified.* The rotation and arming times of both S&As were within the required limits (Section 4.10).
Certify that the OFI is capable of launch readiness checkout after the ground system has been connected on the launch pad.	3.2.1.6.2--Instrumentation. The OFI shall be capable of launch readiness checkout after ground system connection on the launch pad.	*Certified.* The 0 percent and 75 percent calibration checks of the OFI verified launch readiness after ground system connection on the launch pad (Section 4.10).
Certify proper operation of the OPT during flight.	3.2.1.6.2.1 The OPT shall monitor the chamber pressure of the RSRMs over the range from 0 to 1,050 ±15 psi. They shall operate in accordance with ICD 3-44005...	*Certified.* The OPTs properly monitored the chamber pressure and operated in accordance with ICD 3-44005. Recorded pressure data and values are discussed in Section 4.4 of this volume.

Certify that the systems tunnel properly : 1) attaches to the case, 2) accommodates the government-furnished equipment (GFE) and linear shaped charge (LSC), and 3) provides OFI, GEI, and heater cables.	3.2.1.10.1 When exposed to the thermal environments of 3.2.7.2, the tunnel floorplates and tunnel cables will be maintained at a temperature at or below that specified in ICD 3-44002.	*Certified.* Postflight evaluation showed no evidence of heat damage to the systems tunnel or adjacent cork, cables, and seams (Table 4.8.3). Proper case attachment and accommodation of the GFE, LSC, and cabling was also verified. A detailed systems tunnel evaluation is in Volume IV of this report.
Certify the performance of the field joint heater and the sensor assembly so it maintains the case field joint at 75°F minimum. Field joints shall not exceed 130°F.	3.2.1.11.a The case field joint external heater and sensor assembly shall maintain the case field joint O-ring seals between 75° and 130°F at launch...	*Certified.* The joint heaters maintained all field joint sensors between 90° and 108°F during the prelaunch period. Sensor temperatures between 85° and 122°F ensure O-ring temperatures are between 75° and 130°F.
Certify that each field joint heater assembly meets all performance requirements.	3.2.1.11.1.2--Power Supply. Each field joint external heater assembly shall meet all performance requirements... as defined in ICD 3-44005.	*Certified.* All field joint external heaters met all the performance requirements. A high voltage spike was noted on the LH aft heater but was determined to be a sensor error (Section 4.8.3).
Demonstrate isolation of subsystem anomalies if required on seventh flight (360L007) hardware.	3.2.3.3 Isolation of anomalies of time-critical functions shall be provided such that a faulty subsystem element can be deactivated without disrupting its own or other subsystems.	No subsystem anomalies of time critical functions were detected on flight set 360L007.

Demonstrate RSRM capability of assembly/disassembly in both the vertical and horizontal positions.	3.2.5.1 The RSRM shall be capable of assembly/disassembly in both the vertical and horizontal positions. The RSRM shall be capable of vertical assembly in a manner to meet the alignment criteria of USBI-10183-0022 without a requirement for optical equipment.	RSRM vertical assembly in accordance with USBI-10183-0022 was demonstrated in the vehicle assembly building (VAB) prior to pad rollout. No vertical disassembly was required. Postflight horizontal disassembly was accomplished at the Hangar AF facilities.
Demonstrate that the RSRM and its components are protected against environments during transportation and handling.	3.2.8.c The RSRM and its components...are adequately protected, by passive means, against natural environments during transportation and handling.	There were no anomalous readings from the transportation monitor units, demonstrating that the RSRM and its components are protected against environments during transportation and handling.
Demonstrate remove and replace capability to the functional LRU.	3.4.1 The maintenance concept shall be to "remove and replace"...in a manner which will...prevent deterioration of inherent design levels of reliability and operating safety at minimum practical costs.	360L007 RH and LH inner and outer igniter gaskets were replaced at KSC due to concerns about subsurface defects in gasket elastomer seal (Section 3.1.9.3).
Certify by inspection all RSRM seal performance.	3.2.1.2 Redundant, verifiable seals shall be provided for each pressure vessel leak path. Both the primary and secondary seals shall provide independent sealing capability through the entire ignition transient and motor burn without evidence of blowby or erosion.	*Certified.* No motor pressure reached any of the field or case-to-nozzle joint seals (Section 4.11.3).

Inspect the factory joint insulation for accommodation of structural deflections and erosion.	3.2.1.2.2.a Sealing shall accommodate any structural deflections or erosion which may occur.	The factory joint insulation remained sealed and accommodated all deflection and erosion (Section 4.11.1).
Certify that at least one virgin ply of insulation exists over factory joint at end of motor operation.	3.2.1.2.2.d The insulation shall provide one or more virgin ply coverage at end of motor operation. The design shall perform the seal function throughout SRM operation.	*Certified.* Preliminary inspections indicate adequate factory joint insulation ply coverage (Section 4.11.1). Detailed insulation inspection results are in Volume III of this report.
Certify that the field and case-to-nozzle joint seals, factory joint insulation, flex bearing seals, ignition system seals, and nozzle internal seals operate within the specified temperature range resulting from the natural and induced environments.	3.2.1.2.1.b--Field and Nozzle/Case Joint Seals... 3.2.1.2.2.b--Factory Joint Insulation... 3.2.1.2.3.b--Flex Bearing Seals... 3.2.1.2.4.b--Ignition System Seals... 3.2.1.2.5.b--Nozzle Internal Seals... ...shall be capable of operating within a temperature range resulting from all natural and induced environments ...all manufacturing processes, and any motor induced environments.	*Certified.* All field joint and case-to-nozzle joint seals, ignition system seals, and internal nozzle seals operated within all induced environments and showed no evidence of heat effects, erosion, or blowby (Section 4.11.3). Evaluation indicates no anomalies with the factory joint insulation (Section 4.11.1) or the flex bearing internal seals. Detailed flex bearing evaluation is in Volume V of this report.
Certify that no leakage occurred through the insulation.	3.2.1.2.2.e The insulation used as a primary seal shall be adequate to preclude leaking through the insulation.	*Certified.* Preliminary inspections showed no evidence of leakage through the factory joint insulation (Section 4.11.1). Detailed post flight evaluations are completed at the H-7 (Clearfield, Utah) facility. Detailed results are in Volume III of this report.

Verify by inspection that no gas leaks occurred between the flex bearing internal components.	3.2.1.2.3.d The flex bearing shall maintain a positive gas seal between its internal components.	*Partially verified.* Preliminary inspection indicates the flex bearing maintained a positive seal within its internal components. Detailed inspection to be completed during flex bearing acceptance testing.
Inspect the risers for damage or cracks that would degrade the pressure holding capability of the case.	3.2.1.3.c The case shall contain risers for attaching the ET/SRB aft attach ring as defined in ICD 3-44004. The risers shall be part of the pressurized section of the case and shall not degrade the integrity of the case.	No damage or adverse effects to the ET attach risers was noted during post-test inspection. Preliminary case inspection results are in Section 4.11.2, and the final case evaluation is in Volume II of this report.
Inspect the case segment mating joints for the pin retention device.	3.2.1.3.g The case segment mating joints shall contain a pin retention device.	The pin retention device on all joints performed as designed (Section 4.11.2). Detailed results are in Volume II of this report.
Inspect the flex bearing for damage due to water impact.	3.2.1.4.6 The nozzle assembly shall incorporate a nozzle snubbing device suitable for preventing flex bearing damage resulting from water impact and shall not adversely affect the nozzle assembly vectoring capability.	Preliminary inspections indicate no anomalous conditions in the 360L007A or 360L007B flex bearings.
Inspect the nozzle for the presence of the environmental protection plug.	3.2.1.4.7.a The nozzle assembly shall contain a covering and/or plug to protect the RSRM...during storage after assembly.	Both nozzle assemblies contained an environmental protection plug, which burst into multiple pieces upon motor ignition.

Certify that the environmental protection plug will withstand SSME shutdown, if incurred.	3.2.1.4.7.b The nozzle assembly shall contain a covering and/or plug to protect the RSRM...in the event of an on-pad SSME shutdown prior to SRB ignition.	*Not required to certify.* No SSME shutdown was required during the actual launch sequence.
Certify the performance of the nozzle liner. Note: SCN 49 has been approved and changes the CEI paragraph wedgeout requirement from "greater than 0.250 in. deep" to "yield a positive margin of safety".	3.2.1.4.13 The nozzle flame front liners shall prevent the formation of: a. Pockets greater than 0.250 in. deep (as measured from the adjacent nonpocketed areas), b. Wedgeouts greater than 0.250 in. deep, c. Prefire anomalies except as allowed by TWR-16340.	*Certified.* No nozzle flame front liner erosion pockets greater than 0.25 in. were noted. All wedgeouts observed occurred postburn and do not affect liner performance. No prefire anomalies were found (Section 4.11.4).
Inspect the ignition system seals for evidence of hot gas leakage.	3.2.1.5.a The ignition system shall preclude hot gas leakage during and subsequent to motor ignition.	No ignition system seals, gaskets, or sealing surfaces showed any evidence of heat effects, erosion, or blowby (Section 4.11.3).
Inspect the igniter for evidence of debris formation or damage.	3.2.1.5.2 ...the igniter hardware and materials shall not form any debris...	Preliminary indications showed no evidence of any igniter debris formation. A complete evaluation is in Volume VI of this report.
Certify that the GEI can monitor the temperature of the SRBs while on the ground at the pad.	3.2.1.6.2.3 The GEI shall monitor the temperature of the SRBs while on the ground....	*Certified.* Extensive monitoring of the GEI was done during the countdown to access the SRM thermal environment and LCC. Detailed results are discussed in Section 4.8.

Inspect the seals for visible degradation from motor combustion gas.	3.2.1.8.1.1.d Insulation shall protect primary and secondary seals from visible degradation from motor combustion gas.	All motor combustion gas was contained by the insulation J-leg on the six field joints and the polysulfide adhesive on the two case-to-nozzle joints. No seals showed evidence of motor combustion gas degradation (Section 4.11.1).
Certify by inspection that the insulation met all performance requirements.	3.2.1.8.1.1.e The insulation shall...meet all performance requirements under worst manufacturing tolerances and geometry changes during and after assembly and throughout motor operation.	*Certified.* Preliminary inspection indicates the insulation met all the performance requirements (Section 4.11.1). Detailed inspection results are in Volume III of this report.
Inspect insulation material for shedding of fibrous or particulate matter.	3.2.1.8.1.1.f Insulation materials shall not shed fibrous or particulate matter during assembly which could prevent sealing.	No shedding of fibrous or particulate matter during assembly was detected (Section 4.11.1 of this volume and Volume III of this report).
Inspect the joint insulation for evidence of slag accumulation.	3.2.1.8.1.1.g The joint insulation shall withstand slag accumulation during motor operation.	No evidence of insulation damage due to slag accumulation was observed (Section 4.11.1 of this volume and Volume III of this report).
Inspect the TPS to ensure that there was no environmental damage to the RSRM components.	3.2.1.8.2 TPS shall insure that the mechanical properties of the RSRM components are not degraded when exposed to the environments...	Postflight inspection revealed excellent TPS condition with no violation of any NSTS debris criteria. No thermal degradation of any RSRM component was noted (Section 4.8.3).

Inspect for thermal damage to the igniter chamber and the adapter metal parts.	3.2.1.8.3 The igniter insulation shall provide thermal protection for the main igniter chamber and adapter metal parts to ensure that RSRM operation does not degrade their functional integrity or make them unsuitable for refurbishment.	Preliminary investigation revealed no thermal damage to the igniter due to lack of insulation functionality. Igniter details are in Volume VI of this report.
Certify that the case components are reusable.	3.2.1.9.a--Reusability of... Case. Cylindrical segments, stiffener segments, attach segments, forward and aft segments (domes), stiffener rings, clevis joint pins.	*Cannot be completely certified at this time.* All case component previous use history is in Section 4.2. No damage was noted to any cylindrical segments, attach segments, forward and aft domes, clevis joint pins, or the stiffener rings and segments on 360L007B (RH) or 360L006A (LH). Reuse criteria are not established until after refurbishment. Detailed case component inspection results are in Volume II of this report.
Certify that the nozzle metal parts are reusable.	3.2.1.9.b, Reusability of... Nozzle Metal Parts--Boss attach bolts.	*Cannot be completely certified at this time.* All nozzle metal part previous use history is in Section 4.2. Preliminary observations showed no damage or corrosion to any nozzle reusable metal parts (Section 4.11.4). Any nozzle metal parts that are determined not to be reusable are discussed in Volume V of this report.

Certify through flight demonstration and a postflight inspection that the flex bearing is reusable.	3.2.1.9.c Reusability of... Flex bearing system - Reinforced shims and end rings, elastomer materials.	*Cannot be completely certified at this time.* The flex bearing previous use history is in Section 4.2. No apparent anomalies were observed with the 360L-007A (LH) or 360L007B (RH) flex bearing (Section 4.11.4). Final reuse criteria cannot be determined until after flex bearing acceptance testing.
Certify that the igniter components are reusable	3.2.1.9.d--Reusability of... Igniter. Chamber, adapter, igniter port, special bolts.	*Cannot be completely certified at this time.* All igniter component previous use history is in Section 4.2. Preliminary postflight inspection revealed nothing that would adversely affect reuse of any igniter part. Detailed inspection results are in Volume VI of this report.
Certify by inspection that the S&A is reusable.	3.2.1.9.e--Reusability of... Safe & Arm Device.	*Cannot be completely certified at this time.* The S&A previous use history is in Section 4.2. Preliminary postflight inspection revealed nothing that would adversely affect reuse of any S&A part. Detailed inspection results are in Volume VI of this report.

Certify by inspection that the OPTs are reusable.	3.2.1.9.f--Reusability of... Transducers	*Cannot be completely certified at this time.* The OPT previous use history is in Section 4.2. All pressure data and preliminary postflight inspection indicate no issues that would adversely affect OPT reuse. Final OPT reuse criteria are established after refurbishment and calibration by the metrology lab.
Inspect the case factory joint external seal for moisture.	3.2.1.12 The factory joint external seal shall prevent the prelaunch intrusion of rain into the factory joints from the time of assembly of the segment until launch... The factory joint seal shall remain intact through flight and, as a goal, through recovery.	The external weatherseal protected the case adequately from assembly until launch. Two of the 14 factory joint weatherseals showed signs of unbonds. A detailed weatherseal evaluation is in Volume III of this report.
Inspect the hardware for damage or anomalies as identified by the failure modes and effects analyses (FMEA).	3.2.3 The design shall minimize the prob-ability of failure taking into consideration the potential failure modes identified and defined by FMEA.	No hardware damage or anomalies identified by FMEAs were found. Specific inspection results are in the individual component volumes of this report.
Determine the adequacy of the design SF, relief provisions, fracture control, and safe life and/or fail-safe characteristics.	3.2.3.1 The primary structure, thermal protection, and pressure vessel subsystems shall be designed to preclude failure by use of adequate design SFs, relief provisions, fracture control, and safe life and/or fail safe characteristics.	Postflight inspections verified adequate design SFs, relief provisions, fracture control, and safe life and/or fail-safe characteristics for the primary structure, thermal protection, and pressure vessel subsystems as documented in this volume and the component volumes of this report.

Determine the adequacy of subsystem redundancy and fail-safe requirements.	3.2.3.2 The redundancy requirements for subsystems...shall be established on an individual subsystem basis, but shall not be less than fail-safe...	No primary subsystem failure was noted; thus, subsystem redundancy and fail-safe requirements were not determined.
Demonstrate isolation of subsystem anomalies if required on seventh flight (360L007) hardware.	3.2.3.3 Isolation of anomalies of time-critical functions shall be provided such that a faulty subsystem element can be deactivated without disrupting its own or other subsystems.	No subsystem anomalies of time-critical functions were detected on flight set 360L007.
Demonstrate RSRM capability of assembly/ disassembly in both the vertical and horizontal positions.	3.2.5.1 The RSRM shall be capable of assembly/ disassembly in both the vertical and horizontal positions. The RSRM shall be capable of vertical assembly in a manner to meet the alignment criteria of USBI-10183-0022 without a requirement for optical equipment.	RSRM vertical assembly in accordance with US-BI-10183-0022 was demonstrated in the VAB prior to pad rollout. No vertical disassembly was required. Postflight horizontal disassembly was accomplished at the Hangar AF (KSC) facilities.
Demonstrate that the RSRM and its components are protected against environments during transportation and handling.	3.2.8.c The RSRM and its components...are adequately protected, by passive means, against natural environments during transportation and handling.	There were no anomalous readings from the transportation modular units, demonstrating that the RSRM and its components are protected against environments during transportation and handling.

Inspect the identification numbers of each reusable RSRM part and material for traceability.	3.3.1.5 Traceability shall be provided by assigning a traceability identification to each RSRM part and material and providing a means of correlating each to its historical records...	Inspection numbers for traceability of each RSRM part and material are provided and are maintained in the Automatic Data Collection and Retrieval (ADCAR) computer system. The past history of all RSRM parts used is in Section 4.2.
Verify the structural SF of the case-to-insulation bond.	3.3.6.1.1.2.a The structural SF for the case-to-insulation bonds shall be 2.0 minimum during the life of the RSRM.	Verification of a 2.0 SF cannot be done by inspection; however, flight performance verified an SF of at least 1.0. Case-to-insulation bond and adhesive bond SF of 2.0 are verified by analysis and documented in TWR-16961.
Verify by inspection the remaining thickness of the case insulation.	3.3.6.1.2.2 The case insulation shall have a minimum design SF of 1.5, assuming normal motor operation, and 1.2, assuming loss of a castable inhibitor.	Preliminary insulation thickness measurements indicate adequate thermal SF near the igniter boss. A final evaluation will be made after the internal insulation thicknesses are measured at the Clearfield (H-7) facility. (Results and verification of SFs are in Volume III of this report.)
Previous objective continued	3.3.6.1.2.3 Case insulation adjacent to metal part field joints, case-to-nozzle joints, and extending over factory joints shall have a minimum SF of 2.0.	See above statement.
Previous objective continued	3.3.6.1.2.4 Case insulation in sandwich construction regions (aft dome and center segment aft end) shall have a minimum SF of 1.5.	See above statement.

Previous objective continued	3.3.6.1.2.6 Insulation performance shall be calculated using actual pre- and post-motor operation insulation thickness measurements.	Standard measurement techniques were used for final evaluation, as discussed in Volume III of this report.
Verify by inspection the remaining nozzle ablative thicknesses.	3.3.6.1.2.7 The minimum design SFs for the nozzle assembly primary ablative materials shall be as listed below... (Values not included here, as detailed results are not available at this writing.)	Preliminary inspections indicate nozzle ablative thicknesses were within design SFs (Section 4.11.4). Detailed results are in Volume V of this report.
Verify the nozzle SFs.	3.3.6.1.2.8 The nozzle performance margins of safety shall be zero or greater...	Verification of SFs cannot be done by inspection. Nozzle margins of safety will be discussed in Volume V of this report.
Inspect metal parts for presence of stress corrosion.	3.3.8.2.b The criteria for material selection in the design to prevent stress corrosion failure of fabricated components shall be in accordance with MSFC-SPEC-522 and SE-019-094-2H.	Inspection of metal parts for the presence of stress corrosion cannot be done visually but will be accomplished during refurbishment. Any stress corrosion found will be reported in Volume II of this report.
Demonstrate remove and replace capability of the functional LRU.	3.4.1 The maintenance concept shall be to "remove and replace"...in a manner which will...prevent deterioration of inherent design levels of reliability and operating safety at minimum practical costs.	360L007 RH and LH inner and outer igniter-gaskets were replaced at KSC due to concerns about subsurface defects in the gasket elastomer seal (Section 3.1.9.3).

3.3 RECOMMENDATIONS

Following is a summary of the recommendations made concerning flight set 360L007. Additional background information can be found in the referenced sections.

3.3.1 Aero/Thermal Recommendations

(Additional information is in Section 4.8.4.)

3.3.1.1 GEI Prediction. Aero/Thermal is anticipating a submodel development effort for the areas of the ET attach ring, field joint, factory joint, systems tunnel, igniter, and nozzle regions to improve predictions. These areas would be encompassed by the global model. The nodes need to be made smaller to refine the model. If the model cannot be satisfactorily refined, all systems with heaters will remain separate models, since at this time these separate models are more accurate.

3.3.1.2 GEI Accuracy. Gage range has been reduced on all joint heater sensors, resulting in better data resolution. It is recommended that the data collection accuracy of all GEI be increased by reducing the gage range and increasing the digital word length. The real fidelity of the KSC ground support equipment (GSE) could then be quantified and conceivably replaced if determined to be inadequate.

3.3.1.3 Local Chilling. Based on data from STS-28R (360H005), STS-29R (360L003), and STS-30R (360T004), local cooling does occur. Due to dissimilar ambient environments on launch day and the day prior to launch, it was not possible to determine local chilling on this flight. A method is being developed by Thiokol personnel to accurately quantify and predict the chill effect.

3.3.1.4 IR Measurements. STI data continue to be much more reliable than IR gun measurements. Comparisons with GEI are within acceptable margins for STI data but are questionable and unpredictable for IR gun data. Future efforts should be made in specifying locations for additional stationary STI cameras to assist in the eventual replacement of the outboard GEI. (Inboard GEI will need to be maintained because the STI cannot reach these blind regions.)

3.3.1.5 SRM Hardware Thermal Assessment. The SRM TPS design, from a thermal perspective, continues to suggest that the worst-case flight design environments of the Integrated Vehicle Baseline Configuration (IVBC-3) and SRB reentry are for the most part overly conservative. An exception to this is the environment in the nozzle base region during reentry when excessive nozzle flame heating and hydrazine fires are present. (See TWR-17542, Vol. 1, STS-29R (360L003) Final Report.) USBI is currently obtaining updated thermal environments for the base region. A followthrough will be made concerning this request.

4

FLIGHT EVALUATION RESULTS AND DISCUSSION

4.1 RSRM IN-FLIGHT ANOMALIES (FEWG report Paragraph 2.1.2)

No IFAs pertaining to flight set 360L007 were identified.

4.2 RSRM CONFIGURATION SUMMARY (FEWG report Paragraph 2.1.3.2)

4.2.1 SRM Reuse Hardware

The case segment reuse history for flight motors 360L007A and 360L007B is shown in Figures 4.2-1 and 4.2-2, respectively. Figures 4.2-3 through 4.2-6 show the LH and RH igniter and nozzle parts reuse, respectively. Nozzle snubber segments were new. Stiffener ring reuse is shown in Figures 4.2-7 through 4.2-10.

4.2.2 Approved RSRM Changes and Hardware Changeouts

A summary of the changes made since 360L006 (STS-34) is below. Complete descriptions of these changes are documented in Thiokol document TWR-50134, Redesigned Solid Rocket Motor Flight Readiness Review--Level II.

Two Class I hardware changes since 360L006 (STS-34):

a. Change leak check port from angled design to straight design (ECP SRM-1612R1) to reduce stress at leak check port location.

b. Eliminate thermocouple wires and associated K5NA closeout from factory joint weatherseal (ECP SRM-1958R2, Crit 1) to prevent seawater from entering factory joint weatherseal after splashdown.

4.2.3 LCC and OMRSD Changes

a. ECP 2219: Revise the contingency procedures for the S&A and the OPT. Add contingency procedures for the field joint temperature, case-to-nozzle joint temperature, nozzle bondline temperature, igniter joint temperature, and case acreage temperature. The reason for the change is to establish an approved contingency procedure for recovering from RSRM LCC redline violations. The change will be incorporated into MSFC document SIE-019-190-214, Solid Rocket Booster Recommended Actions for SRB Redline Violations.

Component	S/N	Previous Use		Total Pressurizations
Forward Dome P/N 1U51473-03	S/N 0000034R2	24B,PVM-1	6	13
Cylinder, Std. Wt. P/N 1U50131-13	S/N 0000022R5	DM-3,QM-3, 5A,13B,22B	12	17
Capture Cylinder, Standard Weight P/N 1U52983-02	S/N 0000017	New	3	7
Cylinder, Lightweight P/N 1U50717-05	S/N 0000074R2	14B,24B	6	13
Capture Cylinder, Lightweight P/N 1U52982-03	S/N 0000045	New	3	7
Cylinder, Lightweight P/N 1U50717-05	S/N 0000080R1	19B	4	13
Capture Cylinder, Lightweight P/N 1U52982-03	S/N 0000040	New	3	7
Attach, Lightweight P/N 1U50716-08	S/N 0000030R1	fretting RSRM-1A	5	20
Stiffener, Lightweight P/N 1U50715-06	S/N 0000056	New	4	11
Stiffener, Lightweight P/N 1U50715-05	S/N 0000047R1	RSRM-1B	7	11
Aft Dome P/N 1U50129-11	S/N 0000046R1	RSRM-1B	6	18

Conclusion: There are no fleet leader components in this assembly.
Fretting has occurred where indicated; all fretting has been repaired

☐ Denotes fleet leader status

A025845a

Figure 4.2-1. Hardware Reuse Summary—360L007A (LH) Case

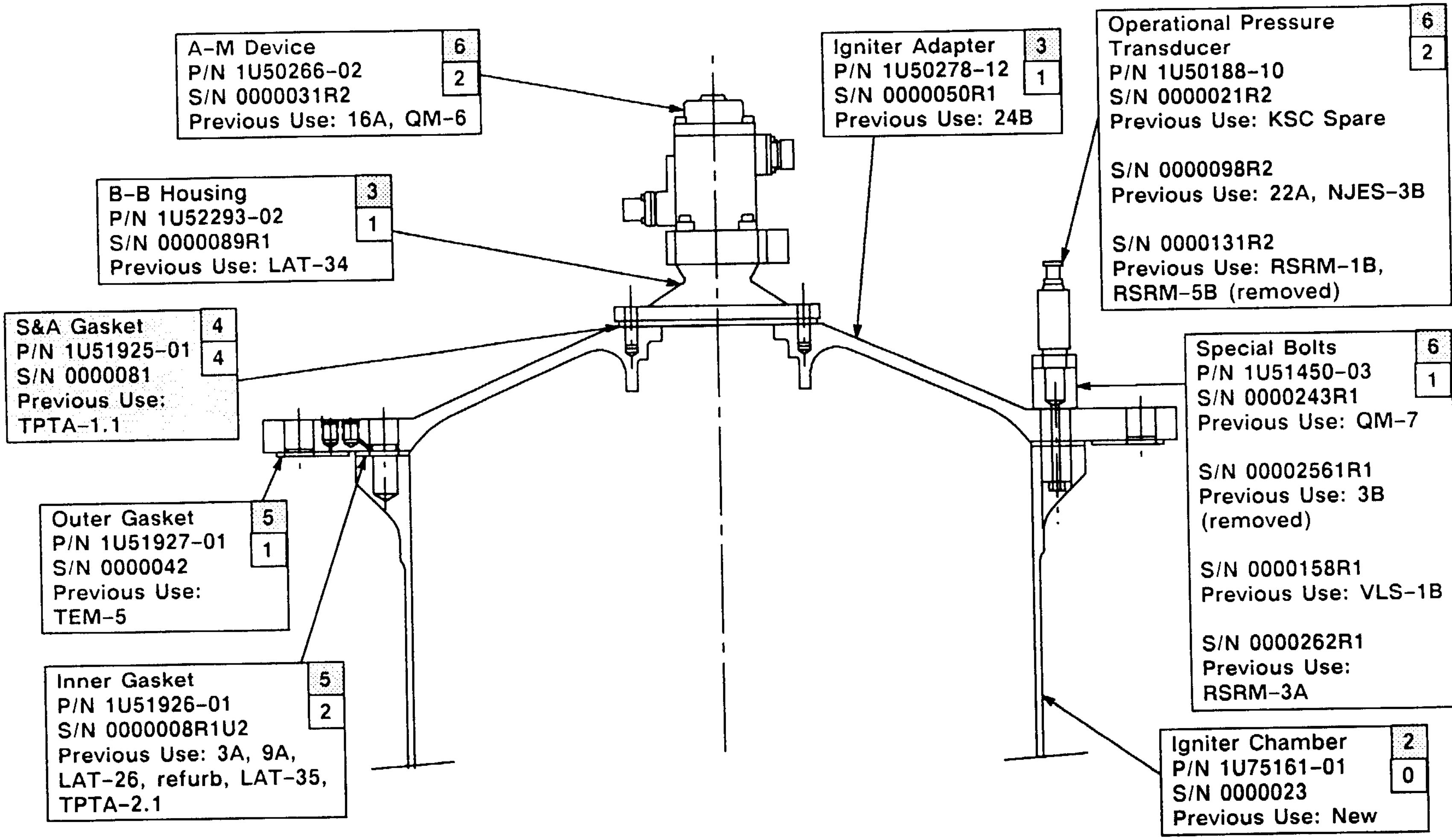
Component	Serial Number	Previous Use	Pressurizations	Total Pressurizations
Forward Dome P/N 1U51473-03	S/N 0000039R1	RSRM-1A	5	13
Cylinder, Std. Wt. P/N 1U50131-13	S/N 0000017R4	DM-4,5A,21A, QM-7	10	17
Capture Cylinder, Standard Weight P/N 1U52983-02	S/N 0000005R1	QM-7	5	7
Cylinder, Lightweight P/N 1U50717-05	S/N 0000084R1	19A	4	13
Capture Cylinder, Lightweight P/N 1U52982-03	S/N 0000043	New	3	7
Cylinder, Lightweight P/N 1U50717-05	S/N 0000096R1	22B	4	13
Capture Cylinder, Lightweight P/N 1U52982-03	S/N 0000042	New	3	7
Attach, Lightweight P/N 1U50716-08	S/N 0000031R1	RSRM-1B	6	20
Stiffener, Lightweight P/N 1U50715-05	S/N 0000029R2	20B,TEM-1	5	11
Stiffener, Lightweight P/N 1U50715-05	S/N 0000030R2	20B,TEM-1	5	11
Aft Dome P/N 1U50129-11	S/N 0000008R3	2A,10B,DM-7	14	18

Conclusion: There are no fleet leader components in this assembly

Denotes fleet leader status

Figure 4.2-2. Hardware Reuse Summary—360L007B (RH) Case

A025846a



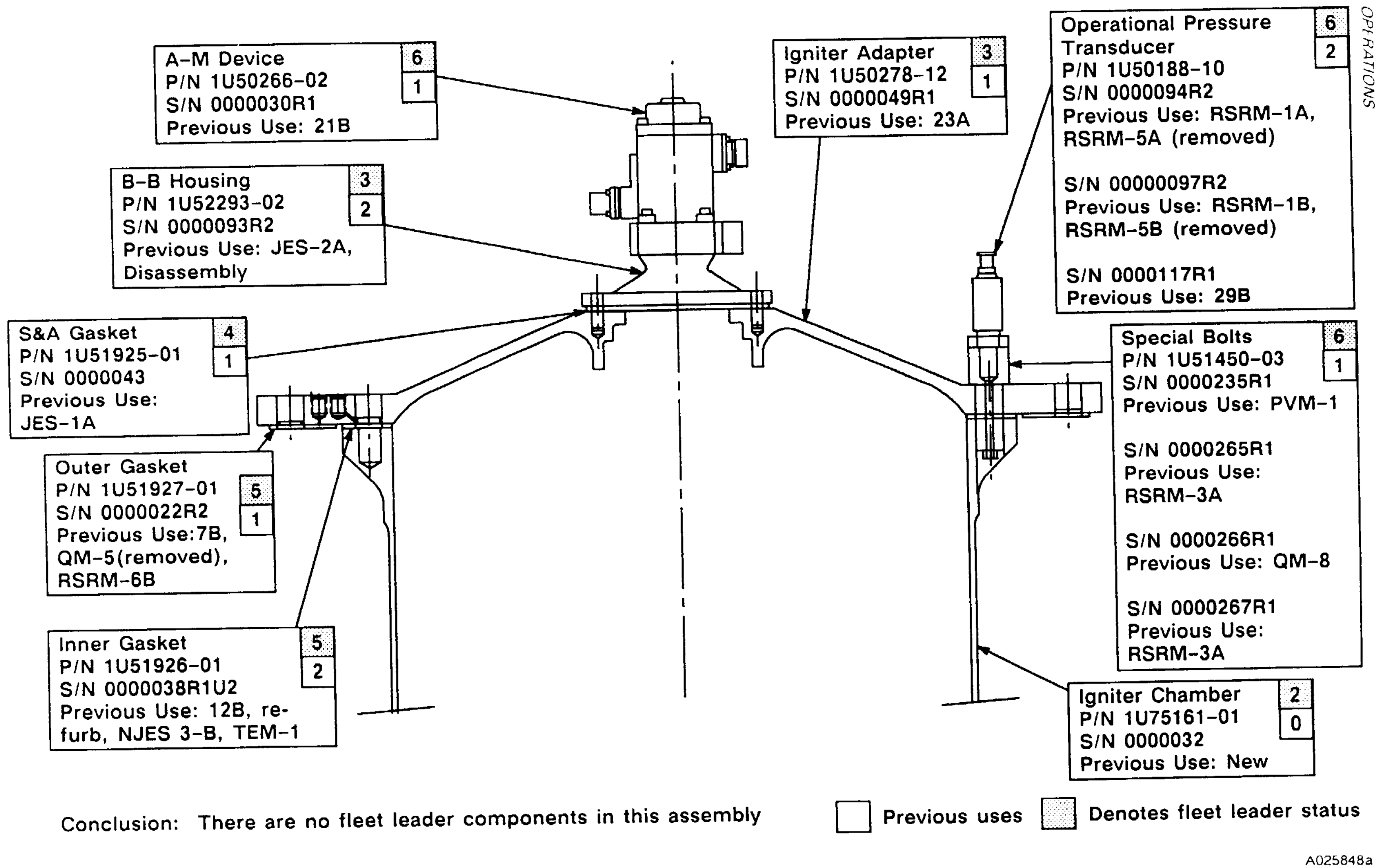
Conclusion: There is one fleet leader component in this assembly

Previous uses

Denotes fleet leader status

Figure 4.2-3. Hardware Reuse Summary—360L007A (LH) Igniter

A025847a



Conclusion: There are no fleet leader components in this assembly

Figure 4.2-4. Hardware Reuse Summary—360L007B (RH) Igniter

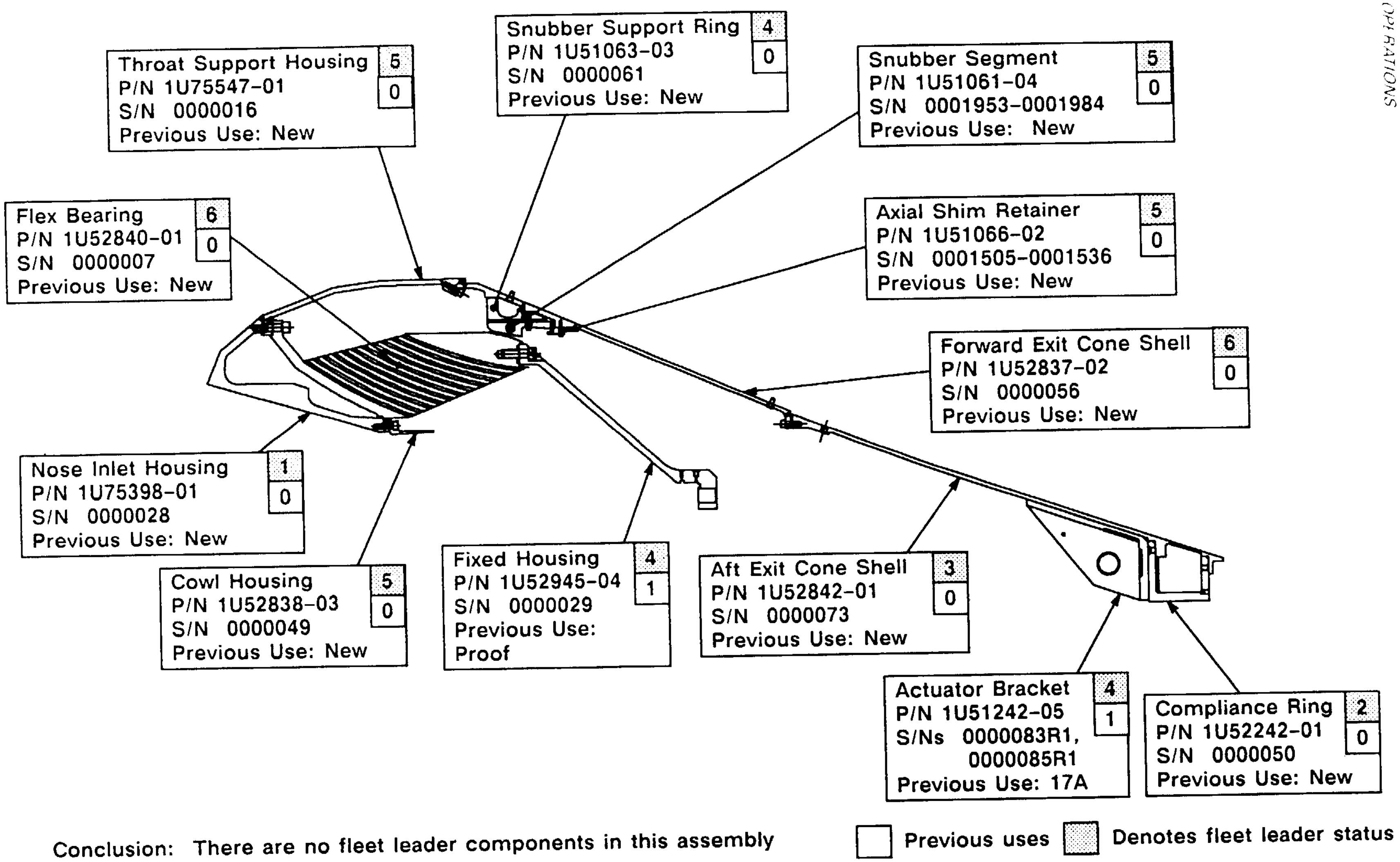


Figure 4.2-5. Hardware Reuse Summary—360L007A (LH) Nozzle

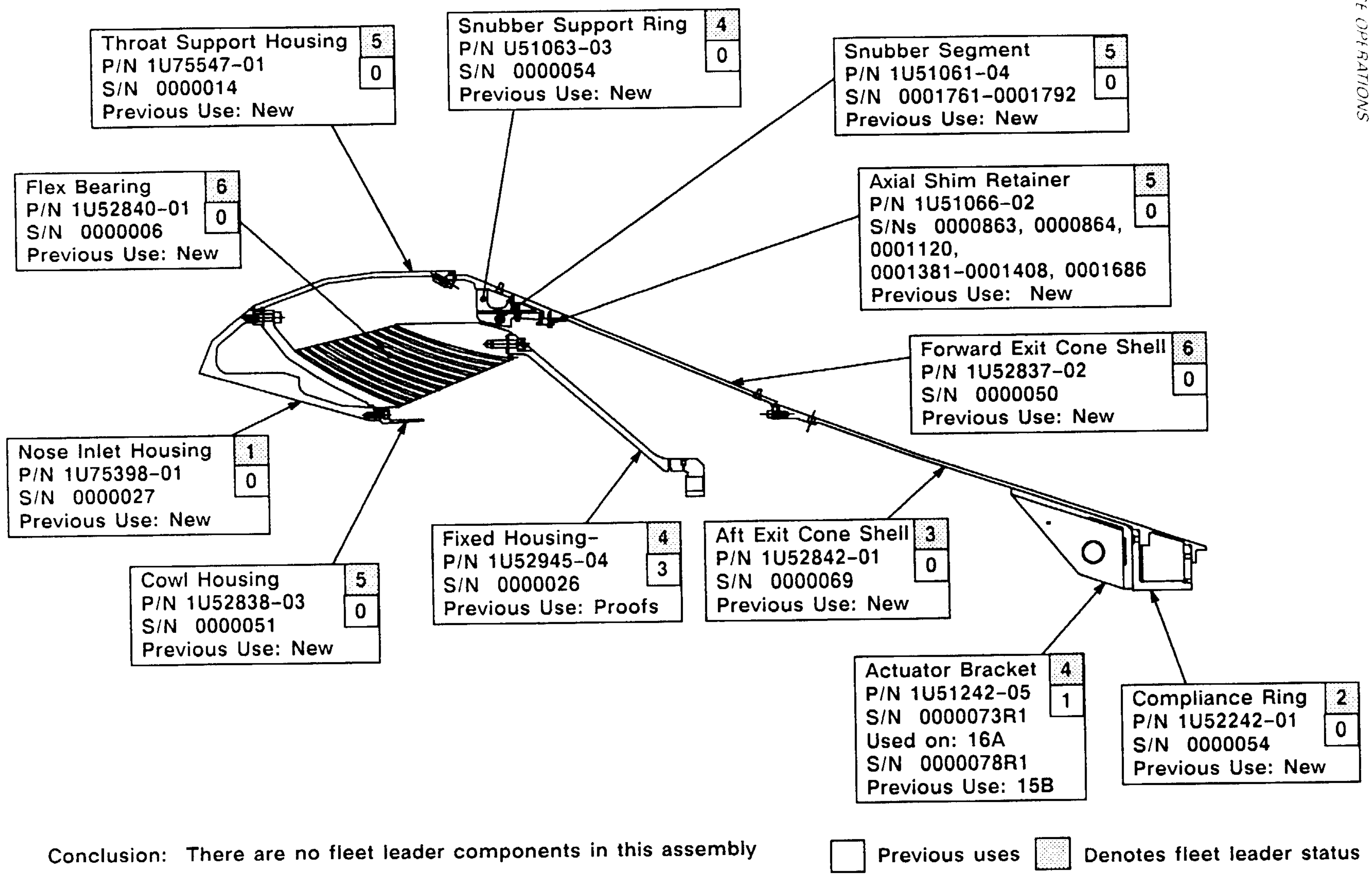


Figure 4.2-6. Hardware Reuse Summary—360L007B (RH) Nozzle

A025850a

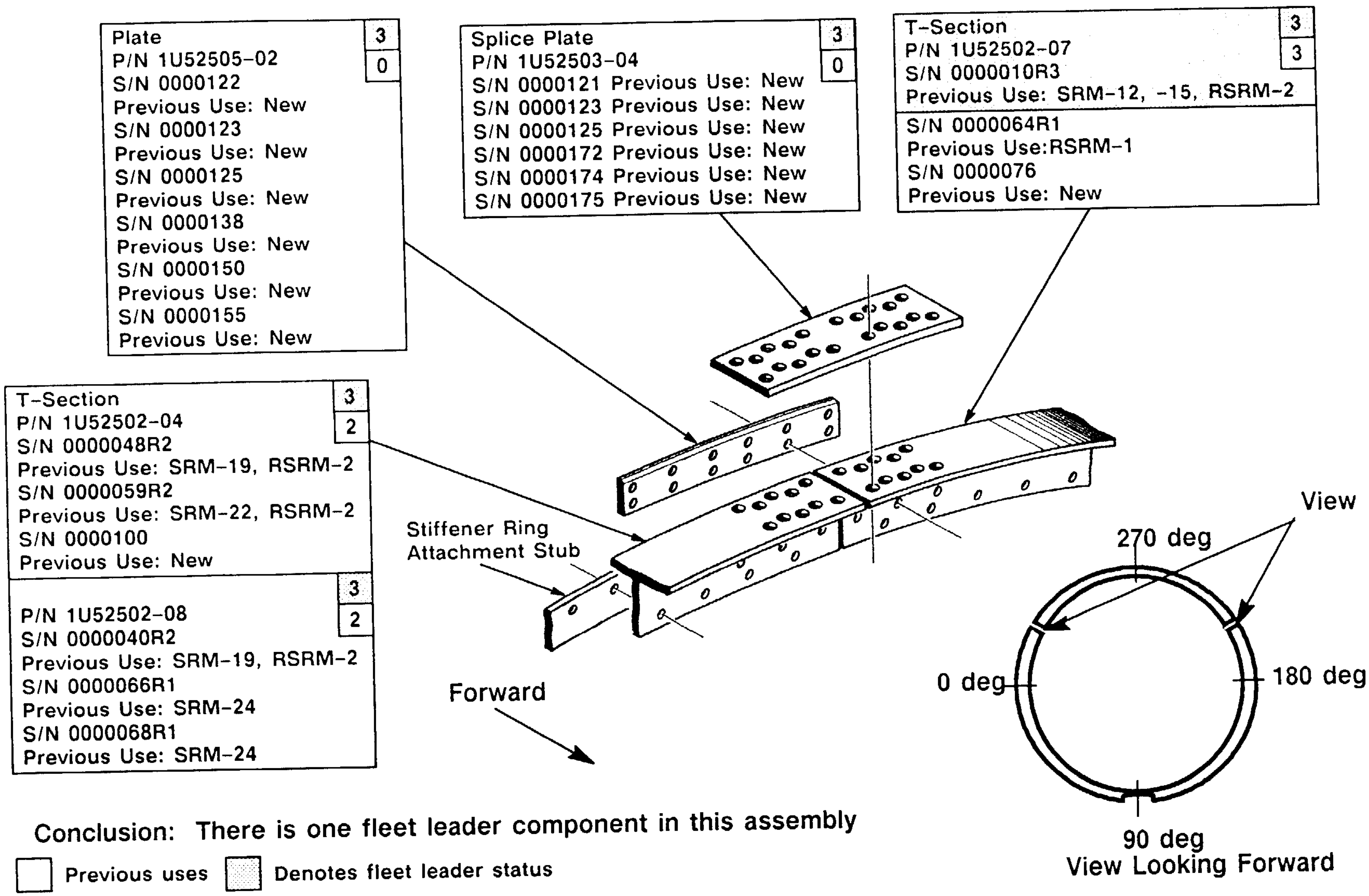
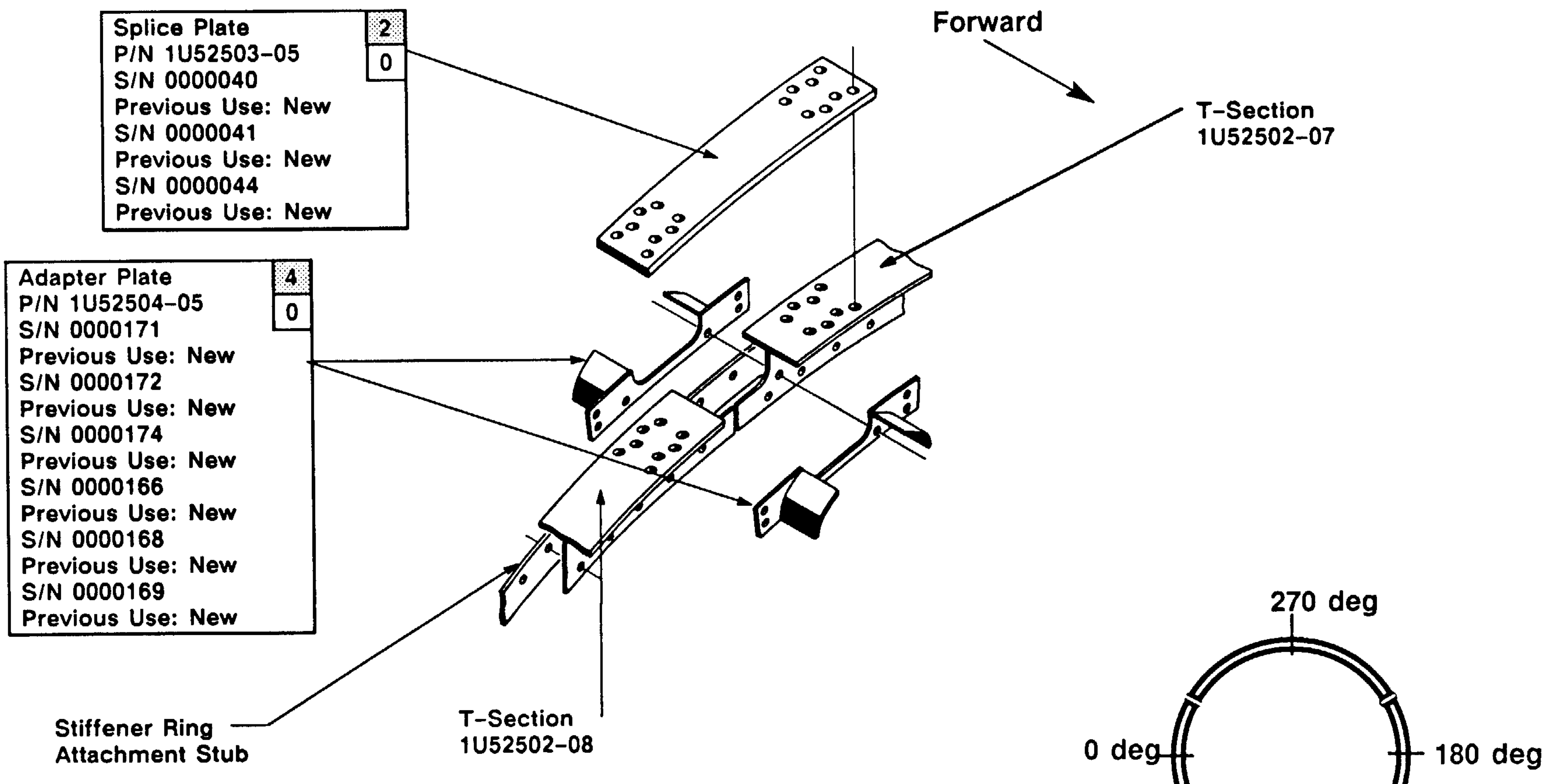


Figure 4.2-7. Hardware Reuse Summary—360L007A (LH) Stiffener Rings at Normal Joints

A025851a



Conclusion: There are no fleet leader components in this assembly

☐ Previous uses

▩ Denotes fleet leader status

Figure 4.2-8. Hardware Reuse Summary—360L007A (LH) Stiffener Rings at Systems Tunnel Joint

A025852a

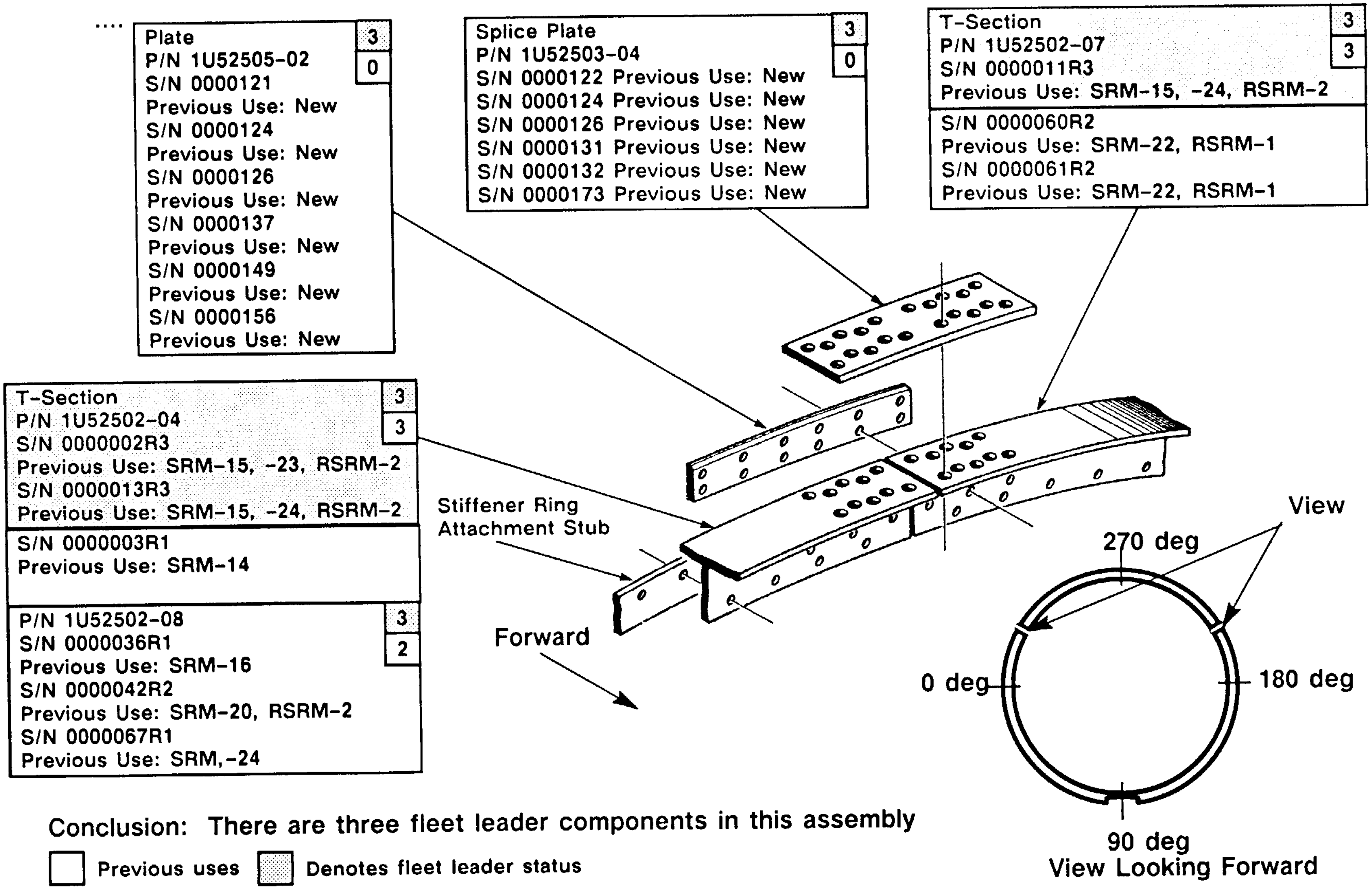
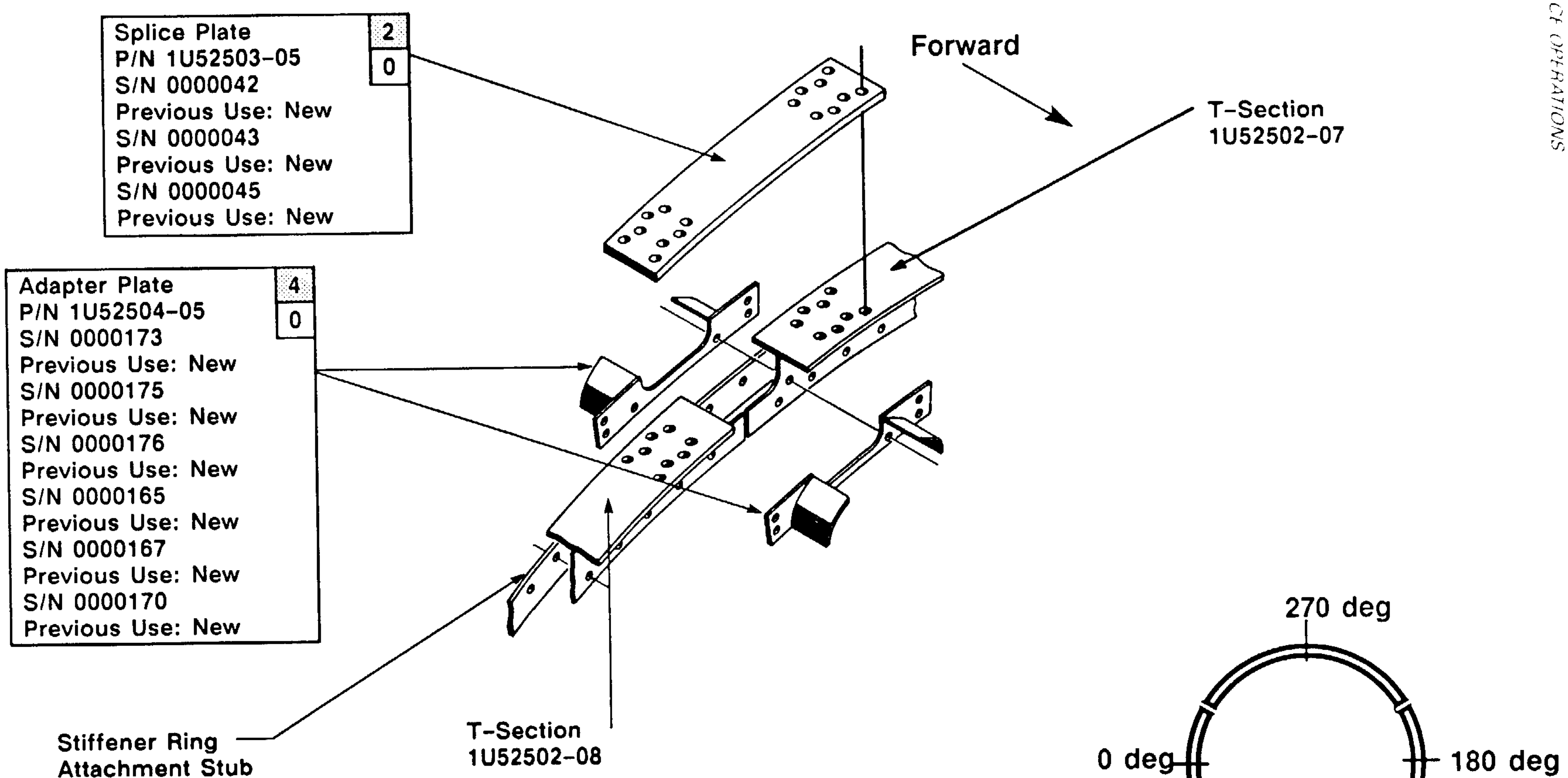


Figure 4.2-9. Hardware Reuse Summary—360L007B (RH) Stiffener Rings at Normal Joints

A025880a



Conclusion: There are no fleet leader components in this assembly

☐ Previous uses

▩ Denotes fleet leader status

Figure 4.2-10. Hardware Reuse Summary—360L007B (RH) Stiffener Rings at Systems Tunnel Joint

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This ECP was disapproved with the rationale that document SE-109-190-2H is not applicable to the RSRM due to Thiokol's flight-by-flight issuance of a TWR, the Prelaunch Countdown Data Book.

b. ECP 2278: Add note to field joint and igniter LCC to implement generic minimum redline temperatures for field joint and igniter joint in the event of primary and secondary heater failure. The reason for the change is that analysis of worst-case tolerance combinations of seal, case, and igniter hardware have established that 78°F for the field joint and 66°F for the igniter joint are the minimum redline temperatures at which the CEI requirement for seal tracking can be maintained. These minimum redline temperatures are effective for any RSRM igniter and field joint if primary and redundant heaters are not operating.

   This ECP was disapproved with the rationale that the change does not give a sufficient temperature margin. In the event both heaters fail, a waiver will be submitted for the specific effectivity.

c. ECP 2323: To establish a minimum temperature to maintain seal tracking margins for flight 360L007. In the event of heater malfunction, the minimum temperature sensor redline for the affected field joint becomes 69°F. This minimum is based on a minimum acceptable O-ring seal temperature using actual, as-built hardware dimensions in calculating O-ring squeeze (TWR-19824) and a +3°F differential temperature.

4.3 SRB MASS PROPERTIES (FEWG report Paragraph 2.2.0)

4.3.1 Sequential Mass Properties

Tables 4.3-1 and 4.3-2 provide 360L007 (STS-33R) LH and RH reconstructed sequential mass properties, respectively. Those mass property sequential times reported after separation reflect delta times from actual separation.

4.3.2 Predicted Data Versus Postflight Reconstructed Data

Table 4.3-3 compares the LH lightweight redesigned shuttle rocket motor (RSRML) predicted sequential weight and center of gravity (cg) data with the postflight reconstructed data. Table 4.3-4 compares the RH RSRML predicted sequential weight and cg data with the postflight reconstructed data. Actual 360L007 (STS-33R) mass properties may be obtained from Mass Properties History Log Space Shuttle 360L007--LH (TWR-17346, dated 5 Aug 1989) and 360L007--RH (TWR-17347, dated 5 Aug 1989).

Table 4.3-1. 360L007A (LH) Sequential Mass Properties

Event Time (sec)	Weight (lb)	Center of Gravity Long	Center of Gravity Lat	Center of Gravity Vert	Moment of Inertia Pitch	Moment of Inertia Roll	Moment of Inertia Yaw
Prelaunch = 0.00	1,256,048.8	1171.216	0.059	0.006	42399.784	879.679	42400.661
Lift-Off = 0.23	1,255,355.9	1171.348	0.059	0.006	42356.568	878.307	42357.445
Intermediate Burn = 20.00	1,015,275.1	1207.838	0.073	0.008	30751.911	762.178	30752.785
Intermediate Burn = 40.00	794,930.3	1231.315	0.093	0.010	21742.171	628.000	21743.039
Max Q = 54.00	665,382.3	1229.061	0.110	0.011	18059.498	551.070	18060.360
Intermediate Burn = 60.00	610,938.0	1226.654	0.120	0.012	16674.024	516.028	16674.883
Intermediate Burn = 80.00	420,824.4	1214.945	0.172	0.018	12032.106	382.862	12032.954
Max G = 87.00	356,709.3	1213.710	0.203	0.021	10637.140	332.405	10637.983
Intermediate Burn = 100.00	251,484.4	1225.613	0.286	0.030	8636.771	244.152	8637.606
Web Burn = 111.32	175,040.2	1266.063	0.408	0.043	7328.101	174.248	7328.929
End of Action Time = 123.66	144,580.9	1315.655	0.492	0.053	6606.016	146.915	6606.839
Separation = 126.20	143,975.4	1317.334	0.495	0.053	6575.401	146.494	6576.228
Max Reentry Q = 321.20	143,568.3	1317.337	0.496	0.052	6554.871	146.134	6555.698
Nose Cap Deployment = 351.20	143,516.0	1317.319	0.496	0.052	6552.099	146.088	6552.926
Drogue Chute Deployment = 351.80	143,515.0	1317.319	0.496	0.052	6552.044	146.087	6552.870
Frustum Release = 372.90	143,478.2	1317.306	0.496	0.052	6550.080	146.054	6550.907
Main Chute Line Stretch = 374.20	143,475.9	1317.306	0.496	0.052	6549.959	146.052	6550.787
Main Chute First Disreefing = 384.30	143,458.3	1317.300	0.496	0.052	6549.016	146.037	6549.843
Main Chute Second Disreefing = 390.20	143,448.1	1317.297	0.496	0.052	6548.463	146.028	6549.290
Nozzle Jettison = 390.90	141,218.7	1307.130	0.495	0.051	6353.277	141.418	6354.084
Splashdown = 416.20	141,175.7	1307.111	0.495	0.051	6350.922	141.380	6351.729

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Table 4.3-2. 360L007B (RH) Sequential Mass Properties

Event Time (sec)	Weight (lb)	Center of Gravity			Moment of Inertia		
		Long	Lat	Vert	Pitch	Roll	Yaw
Prelaunch = 0.00	1,256,025.1	1171.384	0.059	0.006	42389.502	879.649	42390.379
Lift-Off = 0.23	1,255,330.2	1171.515	0.059	0.006	42346.302	878.338	42347.179
Intermediate Burn = 20.00	1,013,170.6	1208.341	0.073	0.008	30644.446	760.912	30645.321
Intermediate Burn = 40.00	792,736.1	1231.457	0.093	0.010	21667.162	626.698	21668.031
Max Q = 54.00	662,986.9	1228.979	0.111	0.011	17997.742	549.660	17998.605
Intermediate Burn = 60.00	608,331.0	1226.456	0.120	0.013	16599.656	513.597	16600.515
Intermediate Burn = 80.00	417,272.6	1214.597	0.174	0.018	11948.669	380.140	11949.516
Max G = 87.00	353,346.2	1213.587	0.205	0.022	10567.208	329.693	10568.051
Intermediate Burn = 100.00	247,943.8	1226.139	0.290	0.031	8573.547	241.007	8574.382
Web Burn = 111.23	172,737.8	1267.708	0.413	0.044	7289.306	172.022	7290.133
End of Action Time = 123.12	144,619.1	1314.887	0.492	0.053	6612.251	146.905	6613.074
Separation = 126.20	143,923.4	1316.776	0.495	0.053	6578.410	146.427	6579.236
Max Reentry Q = 321.20	143,542.9	1316.747	0.496	0.052	6557.602	146.088	6558.428
Nose Cap Deployment = 351.20	143,490.6	1316.729	0.496	0.052	6554.828	146.041	6555.656
Drogue Chute Deployment = 351.80	143,489.6	1316.728	0.496	0.052	6554.773	146.041	6555.599
Frustum Release = 372.90	143,452.8	1316.716	0.496	0.052	6552.810	146.008	6553.637
Main Chute Line Stretch = 374.20	143,450.6	1316.715	0.496	0.052	6552.689	146.006	6553.516
Main Chute First Disreefing = 384.30	143,432.9	1316.709	0.496	0.052	6551.745	145.990	6552.572
Main Chute Second Disreefing = 390.20	143,422.7	1316.706	0.496	0.052	6551.192	145.981	6552.019
Nozzle Jettison = 390.90	141,193.3	1305.696	0.495	0.051	6335.324	141.375	6336.130
Splashdown = 416.20	141,150.3	1305.677	0.495	0.051	6332.967	141.337	6333.773

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Table 4.3-3. 360L007A (LH) Sequential Mass Properties--Predicted Versus Actual Comparisons

	Weight (lb)				Longitudinal cg (in.)			
Event	Predicted*	Actual	Delta	Error (%)	Predicted*	Actual	Delta	Error (%)
Preignition	1,256,049	1,256,049	0	0.00	1,171.216	1,171.216	0.000	0.00
Lift-off	1,255,414	1,255,356	-58	0.00	1,171.342	1,171.348	+0.006	0.00
Action Time	144,345	144,581	+236	0.16	1,313.212	1,315.655	+2.443	0.19
Separation**	143,617	143,975	+358	0.25	1,315.166	1,317.334	+2.168	0.16
Nose Cap Deployment	143,034	143,516	+482	0.34	1,315.519	1,317.319	+1.800	0.14
Drogue Chute Deployment	143,033	143,515	+482	0.34	1,315.519	1,317.319	+1.800	0.14
Main Chute Line Stretch	142,994	143,476	+482	0.34	1,315.505	1,317.306	+1.801	0.14
Main Chute First Disreefing	142,976	143,458	+482	0.34	1,315.499	1,317.300	+1.801	0.14
Main Chute Second Disreefing	142,966	143,448	+482	0.34	1,315.496	1,317.297	+1.801	0.14
Nozzle Jettison	140,737	141,219	+482	0.34	1,305.258	1,307.130	+1.872	0.14
Splashdown	140,694	141,176	+482	0.34	1,305.239	1,307.111	+1.872	0.14

*Based on Mass Properties History Log--Space Shuttle 360L007 (LH), 5 Aug 1989 (TWR-17346)
**The separation longitudinal cg of 1,317.334 is 66 percent of the vehicle length

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Table 4.3-4. 360L007B (RH) Sequential Mass Properties--Predicted Versus Actual Comparisons

	Weight (lb)				Longitudinal cg (in.)			
Event	Predicted*	Actual	Delta	Error (%)	Predicted*	Actual	Delta	Error (%)
Preignition	1,256,025	1,256,025	0	0.00	1,171.384	1,171.384	0.000	0.00
Lift-off	1,255,391	1,255,330	-61	0.00	1,171.511	1,171.515	+0.004	0.00
Action Time	144,320	144,619	+299	0.21	1,312.626	1,314.887	+2.261	0.17
Separation**	143,591	143,923	+332	0.23	1,314.577	1,316.776	+2.199	0.17
Nose Cap Deployment	143,009	143,491	+482	0.34	1,314.927	1,316.729	+1.802	0.14
Drogue Chute Deployment	143,008	143,490	+482	0.34	1,314.927	1,316.728	+1.801	0.14
Main Chute Line Stretch	142,969	143,451	+482	0.34	1,314.913	1,316.715	+1.802	0.14
Main Chute First Disreefing	142,951	143,433	+482	0.34	1,314.907	1,316.709	+1.802	0.14
Main Chute Second Disreefing	142,941	143,423	+482	0.34	1,314.904	1,316.706	+1.802	0.14
Nozzle Jettison	140,711	141,193	+482	0.34	1,303.818	1,305.696	+1.878	0.14
Splashdown	140,668	141,150	+482	0.34	1,303.833	1,305.677	+1.844	0.14

*Based on Mass Properties History Log, Space Shuttle 360L007 (RH), 5 Aug 1989 (TWR-17347)
**The separation longitudinal cg of 1,316.776 is 66 percent of the vehicle length

Some of the mass properties data used have been taken from average actual data presented in the 5 Jun 1989 Mass Properties Quarterly Status Report (TWR-10211-91). Postflight reconstructed data reflect ballistics mass flow data from the 12.5 sample per second (sps) measured pressure traces and a predicted slag weight of 2,000 lb.

4.3.3 CEI Specification Requirements

Tables 4.3-5 and 4.3-6 present CEI specification requirements and predicted and actual weight comparisons. Mass properties data for both RSRMs comply with the CEI specification requirements (CPW1-3600A, Addendum G, Part I).

4.4 RSRM PROPULSION PERFORMANCE (FEWG report Paragraph 2.3.0)

4.4.1 High-Performance Motor (HPM)/RSRM Performance Comparisons

The reconstructed thrust-time traces of flight motor set 360L007 at standard conditions were averaged with the HPM/RSRM population and compared to the CEI specification limits. The results are shown in Figure 4.4-1.

4.4.2 SRM Propulsion Performance Comparisons

The reconstructed RSRM propulsion performance is compared to the predicted performance in Table 4.4-1. The following comments are to explain the table value. The RSRM ignition interval is to be between 202 and 302 ms after ignition command to the NASA standard initiator (NSI) in the S&A. The ignition interval ends when the headend chamber pressure has increased to a value of 563.5 psia. The maximum rate of headend chamber pressure buildup during the ignition transient is required to be less than 115.9 psia for any 10-ms interval. However, no high sample rate ignition data were available for this flight due to the elimination of DFI. Therefore, no rise rate or ignition interval is reported.

Separation is based upon the 50-psia cue from the last RSRM, plus 4.9 sec plus a time delay between the receipt and execution of the command to separate. No time delay is assumed in the prediction. The decay time intervals are measured from the time motor headend chamber pressure has decayed to 59.4 psia to the time corresponding to 85,000 lb of thrust.

4.4.3 Matched Pair Thrust Differential

Table 4.4-2 shows the thrust differential during steady state and tailoff. All the thrust differential values were near the nominal values experienced by previous flight SRMs

Table 4.3-5. 360L007A (LH) Predicted Versus Actual Weight Comparisons (lb)

Item	Minimum	Maximum	Predicted***	Actual	Delta	Error (%)
Inerts						
Prefire, Controlled*		151,076	149,539	149,539	0	0.00
Propellant*	1,104,714		1,106,493	1,106,493	0	0.00
Usable**			1,105,634	1,105,880	+246	0.02
To Lift-Off			535	592	+57	9.63
Lift-Off to Action**			1,105,099	1,105,288	+189	0.02
Unusable			859	613	-246	40.13
Action to Separation			669	546	-123	22.53
After Separation			190	67	-123	183.58
Slag**			1,518	2,000	+482	24.10

*Requirement per CPW1-3600A, Addendum G, Part I (RSRM CEI specification)
**Slag included in usable propellant, lift-off to action
***Based on Mass Properties History Log, Space Shuttle 360L007 (LH), 5 Aug 1989 (TWR-17346)

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Table 4.3-6. 360L007B (RH) Predicted Versus Actual Weight Comparisons (lb)

Item	Minimum	Maximum	Predicted***	Actual	Delta	Error (%)
Inerts						
Prefire, Controlled*		151,076	149,538	149,538	0	0.00
Propellant*	1,104,714		1,106,487	1,106,487	0	0.00
Usable**			1,105,629	1,105,811	+182	0.02
To Lift-Off			535	594	+59	9.93
Lift-Off to Action**			1,105,094	1,105,217	+123	0.01
Unusable			858	676	-182	26.92
Action to Separation			668	635	-33	5.20
After Separation			190	41	-149	363.41
Slag**			1,518	2,000	+482	24.10

*Requirement per CPW1-3600A, Addendum G, Part I (RSRM CEI specification)
**Slag included in usable propellant, lift-off to action
***Based on Mass Properties History Log, Space Shuttle 360L007 (RH), 5 Aug 1989 (TWR-17347)

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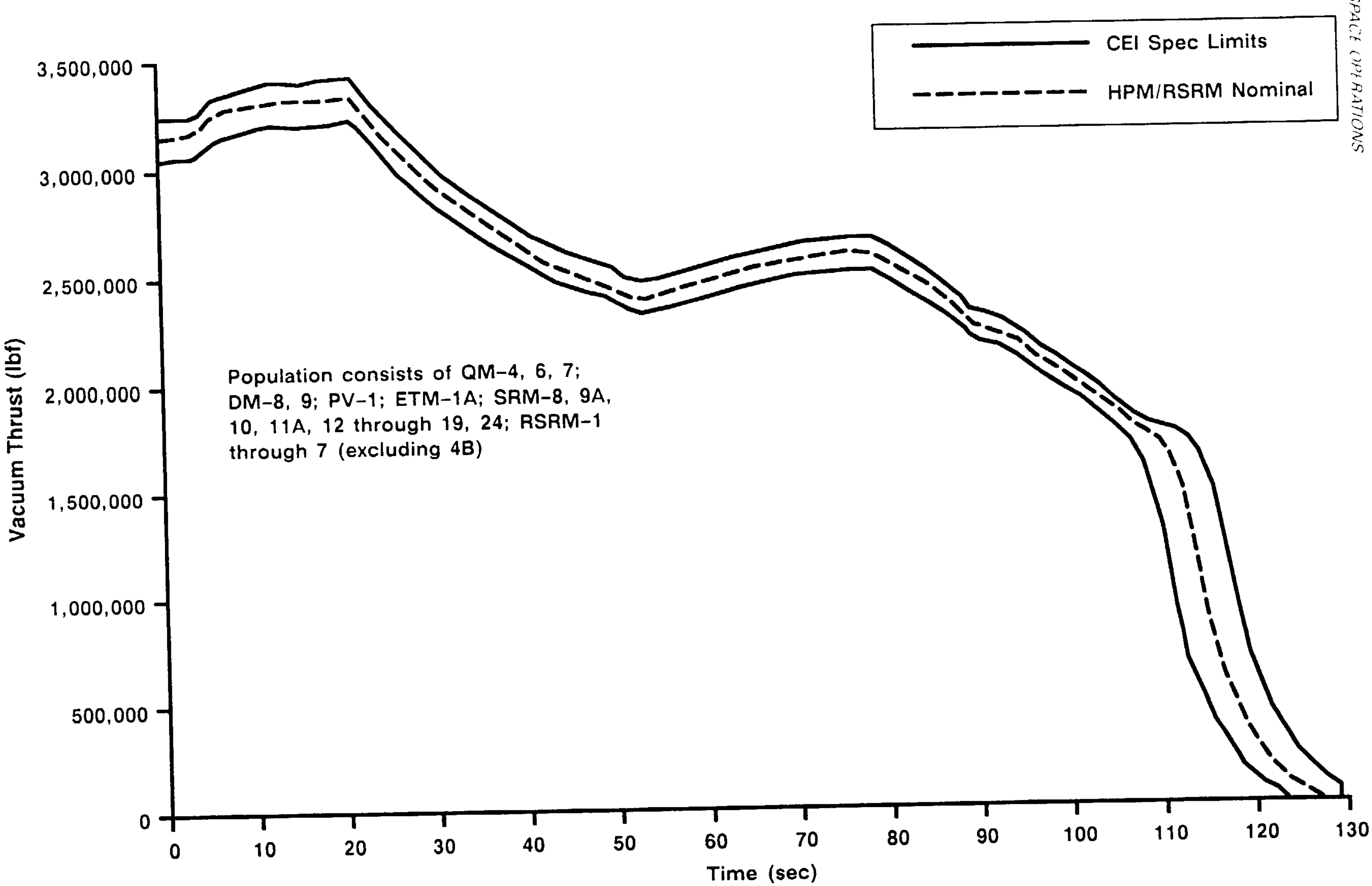

Figure 4.4-1. HPM/RSRM Nominal Thrust Versus CEI Specification

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Table 4.4-1. RSRM Propulsion Performance Assessment

	LH Motor (71 deg)		RH Motor (71 deg)	
	Predicted	Actual	Predicted	Actual
Impulse Gates				
I-20 (10^6 lbf-sec)	65.00	64.78	64.99	65.18
I-60 (10^6 lbf-sec)	173.59	173.11	173.58	173.36
I-AT (10^6 lbf-sec)	297.14	296.75	297.14	296.04
Vacuum I_{sp} (lbf*sec/lbm)	268.5	268.2	268.5	267.6
Burn Rate (in./sec) (60°F)	0.368	0.368	0.368	0.369
Event Times (sec)*				
Ignition Interval	0.232	NA	0.232	NA
Web Time*	110.9	111.1	110.9	111.0
Time of 50-psia Cue	120.8	121.3	120.8	120.2
Action Time*	122.9	123.4	122.9	122.9
Separation Command (sec)	125.7	126.2	125.7	126.2
PMBT (°F)	73.0	71.0	73.0	71.0
Maximum Ignition Rise Rate (psia/10 ms)	91.9	NA	91.9	NA
Decay Time (sec) (59.4 psia to 85 K)	2.8	2.8	2.8	3.4
Tailoff Imbalance	Predicted	Actual		
Impulse Differential (klbf-sec)	NA	+693		

Note: Impulse imbalance = LH motor - RH motor

*All times are referenced to ignition command time except where noted by an *. These times are referenced to lift-off time (ignition interval) and were well within the CEI specification limits. The thrust values used for the assessment were reconstructed at the delivered conditions of each motor.

Table 4.4-2. SRM Thrust Imbalance Assessment

Event	Imbalance Specification (klbf)	Maximum Imbalance (klbf)	Time of Maximum Imbalance (sec)
Steady state (1.0 sec to first web time minus 4.5 sec, lbf, 4-sec average)	85	+29.4	106.5
Transition (first web time minus 4.5 sec to first web time, lbf)	85 - 268 (linear)	+83.0	111.0
Tailoff (first web time to last action time)	710	+110.3	119.6

4.4.4 Performance Tolerances

A comparison of the LH and RH motor calculated and reconstructed parameters at PMBT of 60°F with respect to the nominal values and the SRM CEI specification maximum 3-sigma requirements is given in Table 4.4-3.

4.4.5 Igniter Performance

Due to the elimination of DFI, no evaluation of the igniter performance is possible. Also, no evaluation of the ignition interval, pressure rise rate, and ignition thrust imbalance requirements was possible.

4.5 RSRM NOZZLE TVC PERFORMANCE (FEWG report Paragraph 2.4.3)

The nozzle torque values for motor set 360L007 could not be determined due to DFI elimination on Flight 4 (STS-30R) and subsequent. This section is reserved pending any future motors that incorporate DFI.

Table 4.4-3. SRM Performance Comparisons

	SRM CEI (+/-) Max 3-sigma Variation (%)	Nominal Value*	LH Motor (60°F)	LH Motor Variation (%)**	RH Motor (60°F)	RH Motor Variation (%)**
Web Time (sec)	5.0	111.7	112.4	+0.63	112.3	+0.54
Action Time (sec)	6.5	123.4	124.8	+1.13	124.3	+0.73
Web Time Avg Pressure (psia)	5.3	660.8	655.4	-0.82	655.6	-0.79
Max Headend Pressure (psia)	6.5	918.4	904.0	-1.57	911	-0.81
Max Sea Level Thrust (Mlbf)	6.2	3.06	3.03	-0.98	3.05	-0.33
Web Time Avg Vac Thrust (Mblf)	5.3	2.59	2.57	-0.77	2.57	-0.77
Vac Del Specific Impulse (lbf*sec/lbm)	0.7	267.1	268.1	+0.37	267.4	+0.11
Web Time Vac Total Impulse (Mlbf*sec)	1.0	288.9	288.6	-0.10	288.5	-0.14
Action Time Vac Total Impulse (Mlbf*sec)	1.0	296.3	296.4	+0.03	295.7	-0.20

*QM-4 static test and SRM-8A and 8B, SRM-9A, SRM-10A and 10B, SRM-11A, SRM-13A and 13B flight average at standard conditions

**Variation = ((RSRM-7A - nominal)/nominal) * 100
((RSRM-7B - nominal)/nominal) * 100

4.6 RSRM ASCENT LOADS--STRUCTURAL ASSESSMENT (FEWG report Paragraph 2.5.2)

Motor set 360L007 did not have any DFI installed to evaluate the motor structural performance. This section is reserved pending any future motors that incorporate DFI.

4.7 RSRM STRUCTURAL DYNAMICS (FEWG report Paragraph 2.6.2)

No accelerometer data were available due to the elimination of DFI on Flight 4 (STS-30R) and subsequent. This section is reserved pending the installation of accelerometers on future flight motors.

4.8 RSRM TEMPERATURE AND TPS PERFORMANCE (FEWG report Paragraph 2.8.2)

4.8.1 Introduction

This section documents the thermal performance of the 360L007 (STS-33R) SRM external components and TPS determined by postflight hardware inspection. Assessments of debris, mean bulk temperature predictions, on-pad ambient/local induced environments, LCC, and GEI/joint heater sensor data are also included. Performance of SRM internal components (insulation, case components, seals, and nozzles) is reported in Paragraph 4.11.

4.8.2 Summary

4.8.2.1 Postflight Hardware Inspection. Postflight inspection of the TPS revealed no anomalies or unexpected problems due to flight heating environments. The condition of both SRMs was similar to that of previous flight sets. Table 4.8-1 provides an overall summary of SRM TPS condition. Nozzle erosion is discussed in Section 4.11.4.

4.8.2.2 Debris Assessment. NSTS debris criteria for missing TPS were not violated. The TPS cork pieces that were missing were all caused by nozzle severance debris and/or splashdown loads and debris. A complete SRM debris assessment is given in Section 4.8.3.2.

4.8.2.3 Mean Bulk Temperature Predictions. These temperature predictions were made at different times during the countdown. A discussion of these predictions is presented in Section 4.8.3.3. The final postflight predictions from reconstructed data yielded a PMBT of 71°F and a flex bearing mean bulk temperature (FBMBT) of 75°F.

4.8.2.4 On-Pad Environment Evaluations. The ambient temperature recorded during a 66-hr period prior to launch varied from 50° to 76°F. The normal temperature range experienced during the month of November is from a low of 62°F to a high of 73°F. The 51°F temperature, which occurred over a 6-hr period from midnight to 6:00 a.m. on November 21, represents a minus 1- to minus 2-sigma deviation from the historical

Table 4.8-1. STS-33R RSRM External Performance Summary
(TPS erosion)--Both Motors

Component	TPS Material	Maximum Erosion (in.) Predicted	Measured
Field Joints	Cork	0.003	None
Factory Joints	EPDM	0.014	Not measurable*
Systems Tunnel	Cork	0.014	None
Stiffener Rings	EPDM	0.009	Not measurable*
GEI Closeout	Cork	0.036	Not measurable*
Nozzle Exit Cone	Cork	0.104	NA**

*All evidences of minor erosion were apparent only on the inboard region of the aft segment, where the flight-induced thermal environments are the most severe
**Nozzle exit cones are not recovered

November temperature for the same timeframe. The windspeeds during this same timeframe were lower than historical conditions. See Table 4.8-2 for environmental conditions prior to launch.

4.8.2.5 LCC. No LCC thermal violations were noted. Measured GEI and heater sensor data, as compared with the LCC requirements, are discussed in Section 4.8.3.5. Highlights of the heating operations are summarized as follows.

The igniter heaters were activated for 18 hr, 20 minutes, and maintained the required temperatures. However, the igniter temperature control band was changed from 95° ±5°F to 95° ±1°F. This resulted in more frequent cycling and better heater control. Cooldown, after heater shutoff, occurred over an approximate 7-hr, 13-minute period, and resulted in T-5-minute igniter sensor temperatures from 73° to 76°F. These temperatures were only 5.5°F higher than the preactivation temperatures.

The six field joint heaters performed adequately and as expected with a 17°F sensor temperature range from 90° to 107°F during the LCC timeframe. All 24 field joint sensors recorded temperatures in the expected range. Prior to launch, an LCC contingency was created to lower the minimum redline temperature at any field joint from 85° to 69°F in the event of a complete heater failure. An IPR was written against the LH aft field joint heater voltage, which read 290 V instead of the nominal 209 V. This IPR was dispositioned when it was determined that the voltage must have been nominal because the current reading was nominal. In addition, the heater circuit breaker was not tripped as it would have been had the voltage actually been 290 V.

The SRB aft skirt purge operation was activated approximately 15.5 hr prior to launch. When the LCC timeframe began nearly 6 hr later, all six case-to-nozzle joint temperature readings were 75°F or above. There was concern that the minimum 75°F LCC temperature would not be reached prior to the LCC timeframe, and appropriate action was taken to avoid this occurrence. At the end of the LCC timeframe the temperature range of the case-to-nozzle joint sensors was 82° to 85°F.

4.8.2.6 Prelaunch Thermal Data Evaluation

IR Temperature Measurements. IR measurements from the STI were compared with GEI measurements. IR measurements taken by the IR gun during the T-3-hr ice/debris pad inspection were not reported. The STI temperature measurements were used along with the GEI measurements to monitor SRM surface temperatures.

Table 4.8-2. STS-33R Actual GEI Countdown and Historically Predicted On-Pad November Temperatures (°F) (LCC timeframe temperatures also included)

Component	Daily Cycling November Historical	Daily Cycling Actual GEI	T - 6 Hr to T - 5 Min November Historical	T - 6 Hr to T - 5 Min Actual GEI	T - 6 Hr to T - 5 Min LCC
Igniter Joint					
RH	70-77	62-71	76-100	74-96	66-123
LH	70-76	62-71	75-100	72-96	66-123
Field Joint					
RH Forward	62-77	58-76	95-107	93-108	85-122*
LH Forward	61-77	57-76	94-106	92-101	85-122
RH Center	62-77	57-72	96-107	90-108	85-122
LH Center	61-77	58-73	94-106	92-107	85-122
RH Aft	62-77	57-70	93-105	91-108	85-122
LH Aft	61-77	58-73	95-105	91-107	85-122
Case-to-Nozzle Joint					
RH	65-73	64-66	74-79	78-85	75-115
LH	66-74	64-66	73-82	75-83	75-115
Flex Bearing					
Aft End ring					
RH	65-73	65-67	74-79	82-83	NA-115
LH	66-74	65-69	73-82	82-85	NA-115
Case Acreage (deg)					
RH 45	62-72	58-70	66-72	60-70	--
135	62-75	58-72	66-75	59-72	--
215	63-77	60-76	67-77	60-76	--
270	63-75	59-69	67-75	59-67	35-NA
325	62-73	58-67	66-73	59-67	--
LH 45	62-76	59-75	66-76	59-75	--
135	62-73	59-69	65-73	59-67	--
215	62-73	58-67	65-73	59-67	--
270	63-74	59-70	67-76	59-67	35-NA
325	63-76	59-72	67-76	59-72	--
Local Environment					
Temperature	62-73	50-76	65-70	59-73	38-99
Windspeed (kt)	12	2-13	12	2-13	24
Wind Direction†	N	All dir	N	NE-W	SW-SE
Cloud Cover		Clear		Clear	

*Field joint sensor lower limit will drop from 85° to 69°F in the case of a complete heater failure

Temperatures varied between 64° and 66°F during the T-3-hr pad inspection for both STI and GEI temperatures. A complete evaluation of the IR data is found in Section 4.8.3.6.

4.8.2.7 Prelaunch Hardware Anomalies. There were no prelaunch hardware anomalies.

4.8.3 Results Discussion

4.8.3.1 Postflight Hardware Inspection. Following the recovery of the STS-34R SRBs, a postflight inspection of the external hardware was conducted at the SRB disassembly facility (Hangar AF). TPS performance was considered to be excellent in all areas, with external heating and recession effects being less than predicted (Table 4.8-1). Predictions due to the worst-case design trajectory environments (Table 4.8-3) will be documented in the SRB Thermal Design Data Book, SE-019-068-2H.

The condition of both motors appeared to be similar to previous flight motors, with most of the heat effects seen on the aft segments on the inboard side of the SRBs. The aft segment inboard regions facing the ET experienced high aerodynamic heating normal to protuberance components. They also received the high plume radiation and recirculation heating induced by the adjacent SRB and SSMEs on aft-facing surfaces. In this area there was slight charring of the TPS over the factory joints, the stiffener rings and stubs, and GEI cabling runs. A concise summary of the external hardware condition is shown in Table 4.8-4.

Field Joints. All field joints on both motors were in excellent condition. There were no signs of ablation on any of the joint protection systems (JPS), with only slight paint blistering on the cork cover. The paint on the K5NA closeout aft of the cork was also slightly darkened and blistered, with occasional pitting. This was probably due to aerodynamic heating and the result of aft edge hits from water impact and nozzle severance debris. All K5NA repair locations were intact over the trunnion/vent valve locations, with the exception of the LH aft field joint which had two circumferential cracks at the 30-deg trunnion location. The cracks were about 2 in. long and did not exhibit loose material or any heat effects. The LH forward field joint had two small impact marks on the forward edge and a series of small surface cracks in between. These also were not heat affected.

Factory Joints. The factory joints on each of the motors were in very good condition. The only signs of heat effect experienced on the factory joints were located on the aft

Table 4.8-3. SRB Flight-Induced Design Thermal Environments

Thermal Environment	Related Document
Ascent Heating	Document No. STS 84-0575, dated 24 May 1985 Change Notice 2, SE-698-D, dated 30 Apr 1987 Data on computer tapes No. DN 4044 and DN 9068 Change Notice 3, SE-698-D, dated 30 Oct 1987. Tape No. DP 5309
Base Recirculation Heating	Document No. STS 84-0259, dated Oct 1984 Change Notice 1, SE-698-D, dated 30 Sep 1987
SSME and SRB Plume Radiation	Document No. STS 84-0259, dated Oct 1984 Change Notice 1, SE-698-D, dated 30 Sep 1987
SSME Plume Impingement After SRB Separation	Document No. STS 84-0259, dated Oct 1984 Change Notice 1, SE-698-D, dated 30 Sep 1987
Reentry Heating	Document No. SE-0119-053-2H, Rev D, dated August 1984, and Rev E, dated 12 Nov 1985

Table 4.8-4. STS-33R SRM External Performance Summary (both motors)

Component	TPS Material	Performance	Recovered Hardware Performance Assessment
Field Joints	Cork	Typical	All JPS in excellent condition; slight paint blistering; pitting on aft edge of JPS K5NA closeout; all but one K5NA repair intact over trunnion/vent valve locations; two circumferential cracks on LH aft field joint at 30-deg trunnion locations
Factory Joints	EPDM	Typical	All factory joints in very good condition; typical heat-affected areas on aft segment joints on inboard side of both motors; forward and aft edge unbonds on two (one on each motor) weatherseals with no evidence of sooting; a 1 in. circumferential by 2 in. axial by 1/2-in.-deep gouge occurred on the aft end of forward center factory joint at or after splashdown
Systems Tunnel Heater Cable	Cork/K5NA	Typical	Cork TPS adjacent to tunnel floor plate in JPS excellent condition; very little paint blistering; K5NA closeout in excellent condition on both cables and seams
Stiffener Rings	EPDM	Typical	Good condition--No deviations from normal postflight appearance; charring and discoloration on all edges and inboard top surfaces; Instafoam ramps chunked out on all rings at outboard locations of both motors due to water impact; cracks observed in the K5NA of both middle stiffeners

90407-7.1

Table 4.8-4. STS-33R SRM External Performance Summary (both motors) (Cont)

Component	TPS Material	Performance	Recovered Hardware Performance Assessment
GEI Closeout	Cork/K5NA	Typical	Very good condition, with slight paint blistering; a few small cork pieces missing on GEI cable runs--All within established NSTS debris criteria and all caused by nozzle severance and/or splashdown loads and debris
Aft Kick Ring Joint	Cork	Typical	Good condition from thermal perspective; shielded from radiation by kick ring; no splashdown damage; nozzle exit cone cork unknown; aft exit cones not recovered
Motor Case	NA	Typical	No hot spots or abnormal discoloration of the case paint due to external or internal heating; aft segments extensively sooted

90407-7.2

segments of each motor. There was only slight ablation, charring, and discoloration on the inboard regions of the aft segment factory joints. This occurred between approximately 220 and 320 deg circumferentially on each motor. Again, these are all normal occurrences that have been consistently observed on previous flight motors. Two weatherseals (one on each motor) showed signs of both forward and aft edge unbond regions. No evidence of sooting was found under these unbonds.

Systems Tunnel. The cork TPS adjacent to the systems tunnel floor plate was in excellent condition. There was very little paint blistering. All K5NA closeouts over cables and tunnel seams were in excellent condition.

Stiffener Rings. The stiffener ring TPS was generally in very good condition with only slight thermal degradation. The major heat-affected area was again predominantly in the 220- to 320-deg sector, with the EPDM on the outer flange showing signs of brown charring. This region was subjected to aeroheating along the outboard tip forward face, while the aft face and top surfaces experienced radiant heating. The K5NA TPS on the top surfaces of the stubs was also slightly charred in the same regions, with intermittent pitting around the whole circumference.

GEI Closeout. The cork and K5NA TPS covering the GEI and cableways was generally in good condition. Very little heat effect was observed, consisting of only slight paint discoloration and blistering. Some of the GEI cable runs had small areas of missing cork on the aft edges of the runs at intermittent regions. These minor cork losses were all attributed to aft edge hits caused by nozzle severance debris impact during reentry, splashdown loads, and handling problems.

4.8.3.2 Debris Assessment. NSTS debris criteria for missing TPS were not violated. The TPS cork pieces that were missing were all caused by nozzle severance debris and/or splashdown loads and debris. There were a total of four aft edge hits--three on the LH motor and one on the RH motor. The largest GEI cork piece missing was approximately 2.5 by 2.5 by 0.5 in., or 3.1 $in.^3$. This piece was located at Station 691 at approximately 240 deg. It was either a handling or a splashdown scrape and left a clean substrate.

This flight set is the first flight to use stencils in place of labels to mark the GEI measurement stimulation identification number (MSID) locations on the case surface. The action of removing these labels resulted from debris concerns raised during STS-30R postflight inspection, when many labels were missing. The epoxy closeout over the GEI MSID labels, generally up to 0.125 in. thick, became the material of debris concern.

4.8.3.3 Mean Bulk Temperature Predictions. Mean bulk temperature predictions were performed at various times with respect to the launch of STS-33R. They were predicted for the time of launch and are summarized as follows:

	Historical	L-9 Days 13 Nov 1989	L-2 Days 20 Nov 1989	L-24 hr 21 Nov 1989	Postflight
PMBT (°F)	69	73	73	73	71
FBMBT (°F)	74	74	--	--	75

The final postflight predictions from reconstructed data yield a PMBT of 71°F and an FBMBT of 75°F. The prelaunch predicted PMBT was 2°F higher than the postflight predicted PMBT using reconstructed ambient data.

All predictions were based on the following four sources of data:

1. Thiokol Launch Support Services (LSS) office (faxed weather data)
2. KSC weather station (modem transmission)
3. Florida Solar Energy Center (FSEC) (modem transmission)
4. Central Databasing Service (CDS) data collected at HOSC (faxed weather data)

The data from the Thiokol LSS office were used wherever possible and were the primary source of environmental data. The ambient temperature from the KSC weather station was used as the next source along with windspeed and direction from the FSEC. The ambient temperature data from the FSEC were used only when the other sources were unavailable. The FSEC, however, was the sole source for sky temperature and solar flux. The CDS data collected at HOSC during the countdown was the ambient temperature data used during the 66 hr prior to launch.

The FBMBT calculations were not conducted prior to launch since prelaunch estimations indicated that the FBMBT would be approximately 74°F. Postflight predictions placed the FBMBT at 75°F.

4.8.3.4 On-Pad Environment Evaluations. Actual environmental data for the final 24 hr prior to launch can be visualized in Figures 4.8-1 through 4.8-5 and summarized together with GEI in Table 4.8-2. The ambient temperature recorded during a 66-hr

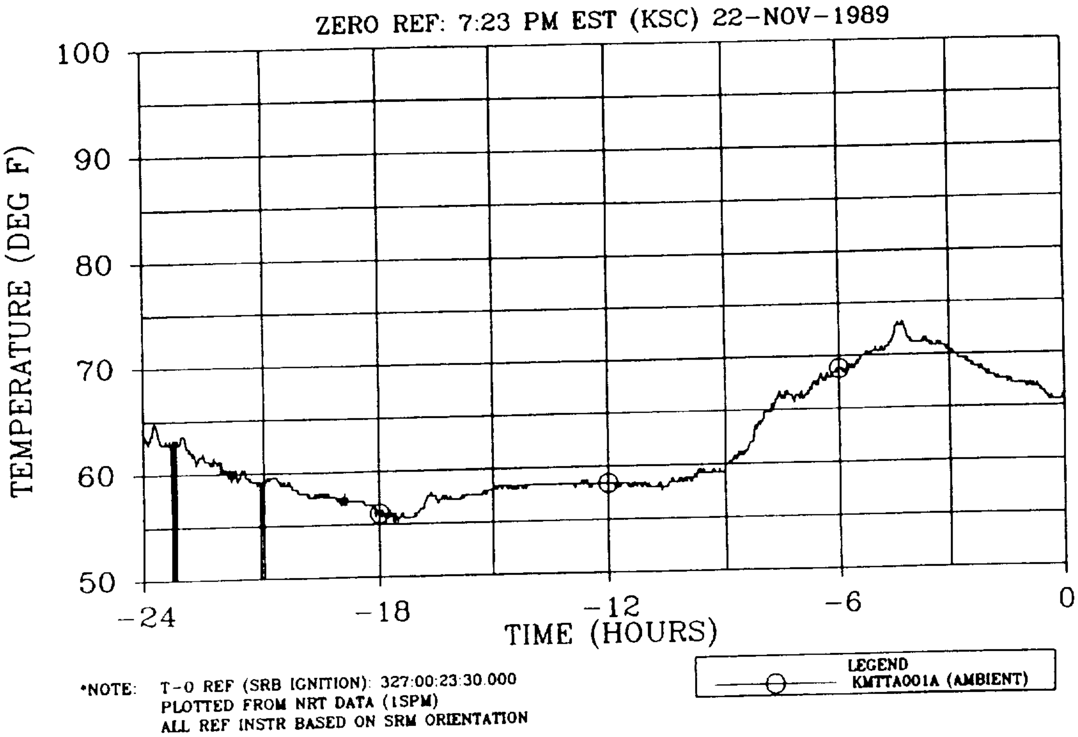

Figure 4.8-1. Ambient Temperatures at Camera Site No. 3

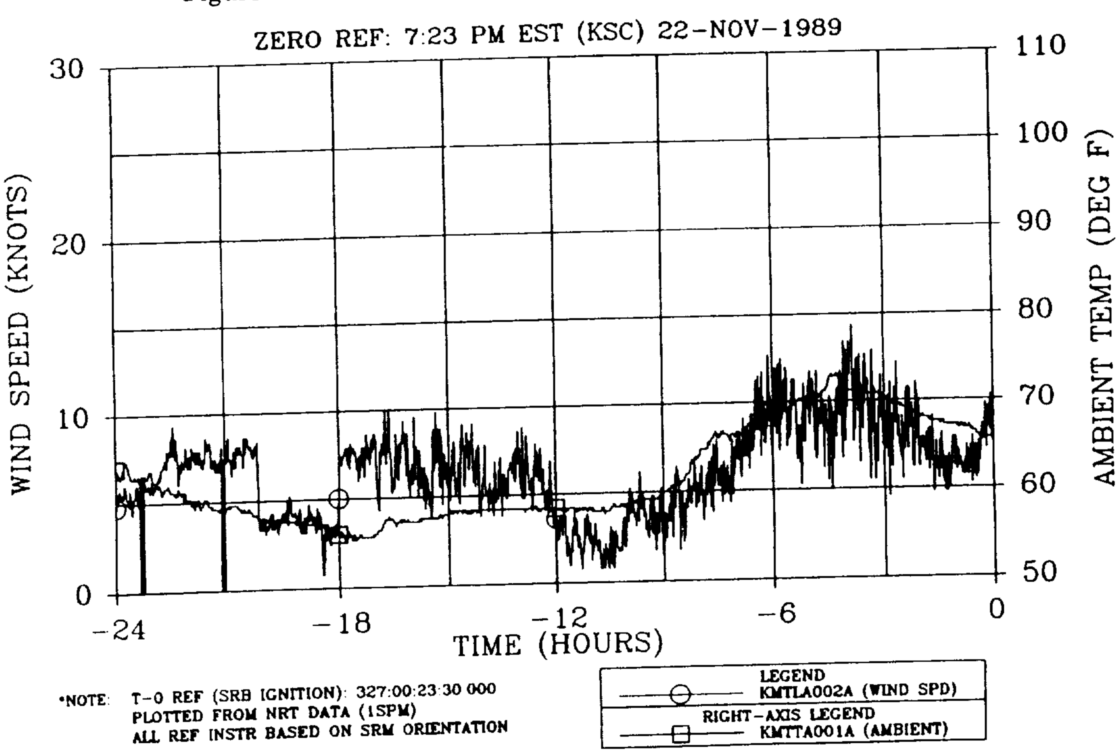

Figure 4.8-2. Windspeed at Camera Site No. 3 (overlaid with ambient)

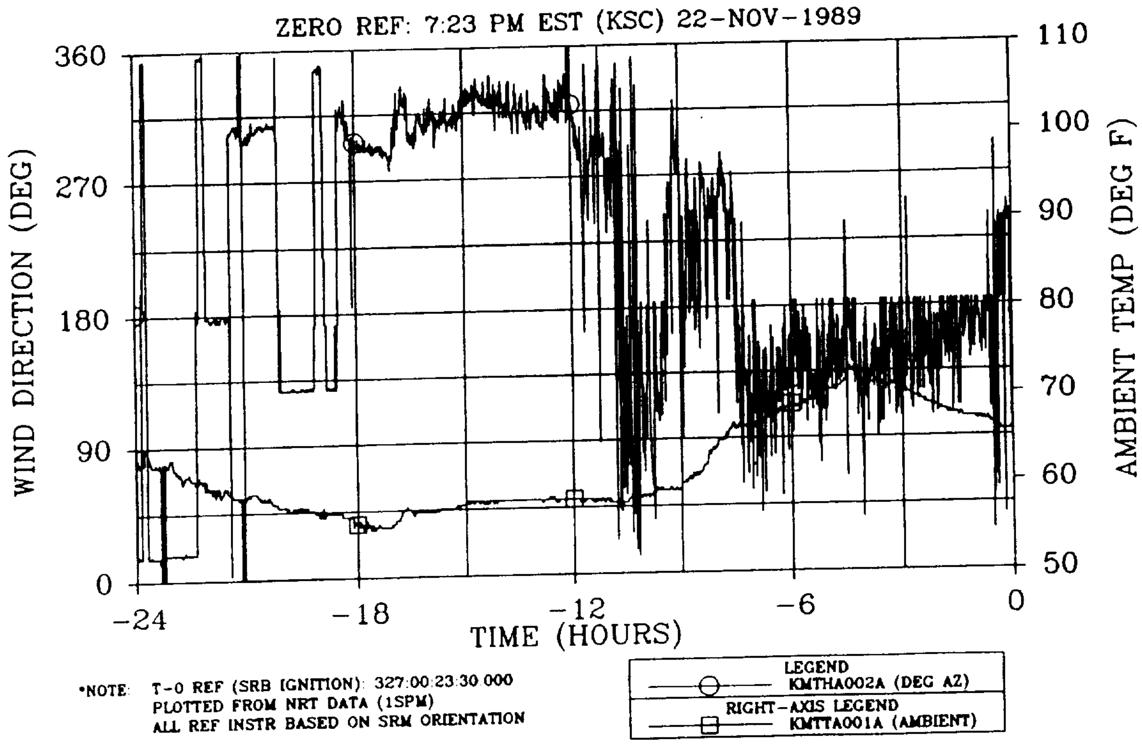

Figure 4.8-3. Wind Direction at Camera Site No. 3 (overlaid with ambient)

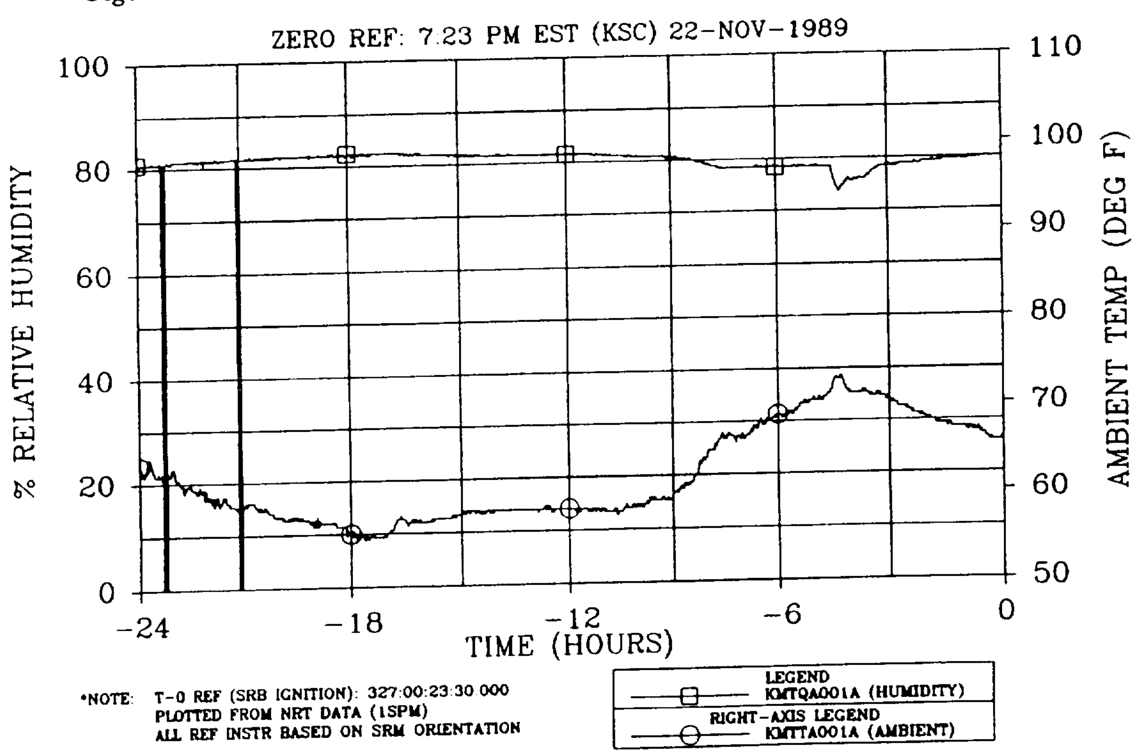

Figure 4.8-4. Humidity at Camera Site No. 3 (overlaid with ambient)

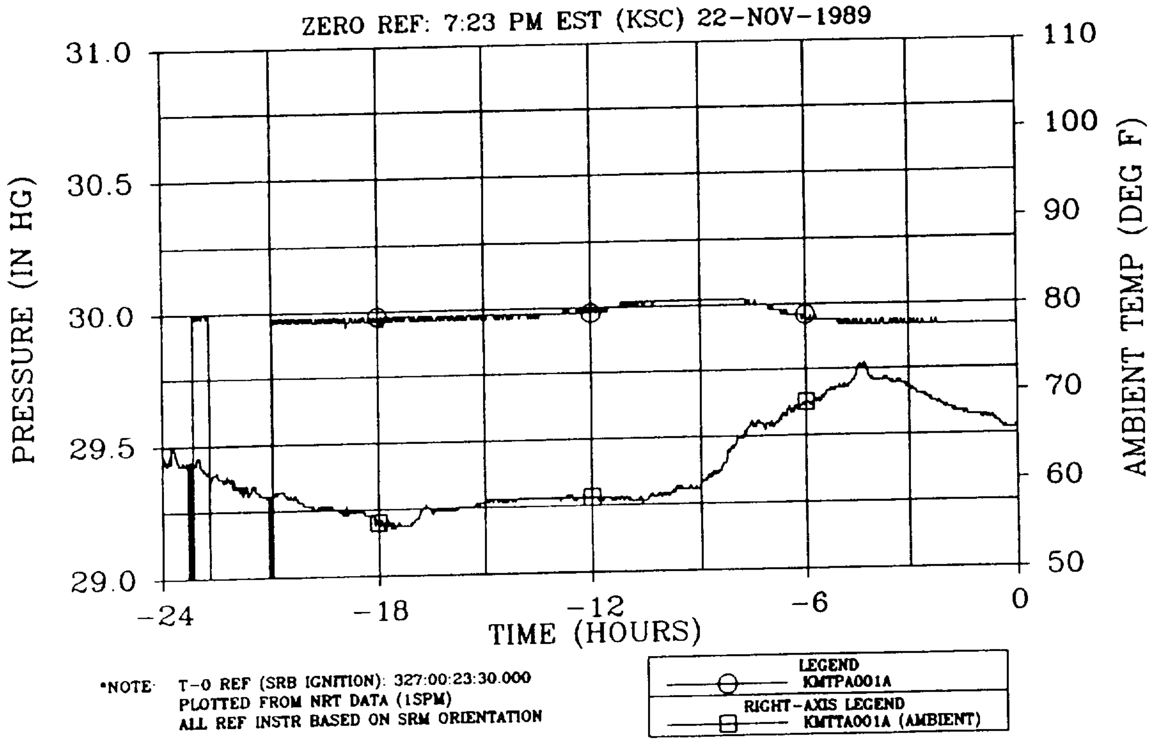

Figure 4.8-5. Barometric Pressure at Camera Site No. 3 (overlaid with ambient)

period prior to launch varied from 50° to 76°F. The normal temperature range experienced during the month of November is from a low of 62°F to a high of 73°F. The 51°F temperature, which occurred over a 6-hr period from midnight to 6:00 a.m. on 21 November, represents a minus 1- to minus 2-sigma deviation from the historical November temperature for the same timeframe. The windspeeds during this same timeframe were lower than historical conditions.

The local on-pad environment due to November historical predictions suggests an average 1°F temperature suppression while the ET is loaded and when winds are from the north. The actual wind direction during the LCC timeframe oscillated from the east to the south. From GEI assessments, there was no evidence of temperature suppression due to ET cooling effects.

4.8.3.5 LCC. No LCC thermal violations were noted. Measured GEI and heater sensor data for the end of the LCC timeframe (T-5 minutes) are presented in Table 4.8-5 and are compared with the LCC requirements.

The igniter heaters were activated for 18 hr, 20 minutes, and maintained the required temperatures. However, the igniter temperature control band was changed from 95° ±5° to 95° ±1°F. This resulted in more frequent cycling and better heater control. Cooldown, after heater shutoff, occurred over an approximate 7-hr, 13-minute period and resulted in T-5 minute igniter sensor temperatures from 73° to 76°F. These temperatures were only 5.5°F higher than the preactivation temperatures.

The six field joint heaters performed adequately and as expected with a 17°F sensor temperature range of 90° to 107°F during the LCC timeframe. All 24 field joint sensors recorded temperatures in the expected range. Prior to launch, an LCC contingency was created to lower the minimum redline temperature at any field joint from 85° to 69°F in the event of a complete heater failure. An IPR was written against the LH aft field joint heater voltage, which read 290 V instead of the nominal 209 V. This IPR was dispositioned when it was determined that the voltage must have been nominal because the current reading was nominal. In addition, the heater circuit breaker was not tripped as it would have been had the voltage actually been 290 V.

The SRB aft skirt purge operation was activated approximately 15.5 hr prior to launch. When the LCC timeframe began, nearly 6 hr later, all six case-to-nozzle joint

Table 4.8-5. STS-33R T-5 Min On-Pad Temperatures (°F)
(represents end of LCC timeframe)

Component	L-12 Hr Predictions*	November Historical	Actual GEI	LCC
Igniter Joint				
RH	73-77	86-88	73-74	66-123
LH	73-77	86-88	74-76	66-123
Field Joint				
RH Forward	96-102	97-103	98-100	85-122**
LH Forward	96-102	97-103	94-97	85-122
RH Center	96-102	97-103	96-100	85-122
LH Center	96-102	97-103	98-101	85-122
RH Aft	96-102	97-103	93-98	85-122
LH Aft	96-102	97-103	97-102	85-122
Nozzle/Case Joint				
RH	82-88	85-87	82-85	75-115
LH	82-88	85-87	82-82	75-115
Flex Bearing Aft End Ring				
RH	82-90	85-87	80-86	NA-115
LH	82-88	85-87	83-83	NA-115
Case Acreage (deg)				
RH 45	--	64-65	66-67	--
135	--	64-65	64-67	--
215	--	67-68	64-70	--
270	62-66	67-68	66-67	35-NA
325	--	64-65	66-67	--
LH 45	--	65-66	64-67	--
135	--	64-65	66-67	--
215	--	64-65	66-69	--
270	62-66	66-67	66-67	35-NA
325	--	66-67	64-65	--
Local Environment				
Temperature	59	65	66	38-99
Wind Speed (kn)	--	12	6-8	24
Wind Direction	--	N	SW	SW-SE
Cloud Cover			Clear	

*Predictions for anticipated launch window at T-5 min
**Field joint sensor lower limit will drop from 85°to 69°F in the case of a complete heater failure

temperature readings were 75°F or above. There was concern that the minimum 75°F LCC temperature would not be reached prior to the LCC timeframe and appropriate action was taken to avoid this occurrence. At the end of the LCC timeframe the temperature range of the case-to-nozzle joint sensors was 82° to 85°F.

IR measurements taken by the IR gun during the T-3-hr ice/debris pad inspection were not reported. The STI temperature measurements were used along with the GEI measurements to monitor SRM surface temperatures. Temperatures varied between 64° and 66°F during the T-3-hr pad inspection for both STI and GEI temperatures.

4.8.3.6 Prelaunch Thermal Data Evaluation. Figures 4.8-6 through 4.8-10 show locations of the GEI and joint heater sensors for the igniter adapter, field joints, case acreage, nozzle region, and aft exit cone, respectively. Figures 4.8-11 through 4.8-40 present November historical predictions. These predictions are based on event sequencing, as specified in Table 4.8-6. Figures 4.8-41 through 4.8-97 show actual STS-33R countdown data.

The ambient temperature was 1- to 2-sigma below the historical value while the vehicle was on the pad. The ambient temperatures the day before launch were about 5°F colder than the normal November temperatures. Despite the actual and historical ambient temperature differences, the November historical on-pad predictions were quite accurate. Only in the ET attach and igniter joint regions did the historical predictions differ significantly from the actual GEI data. The LCC time period (T-6 hr to T-5 minutes) predictions were about 5°F higher than the actual data because the ambient temperatures were about 5°F lower than the historical values (Table 4.8-2). The T-5 minute historical versus actual temperature comparisons were in close agreement except for the actual igniter joint temperatures which were 12° to 14°F lower than the historical average (Table 4.8-5). The L-12-hr predictions of launch time conditions, which incorporate an environmental update for the last 24 hr prior to launch, were in good agreement with the GEI.

Postflight reconstructed predictions of GEI and igniter/field joint heater response were performed using the actual environmental data from the 24 hr prior to launch. A few examples of the predictions, compared with actual measured sensor data, are found in Figures 4.8-98 through 4.8-113. Reasonable agreement is apparent in all areas except the ET attach ring, the left SRB systems tunnel, and the case-to-nozzle

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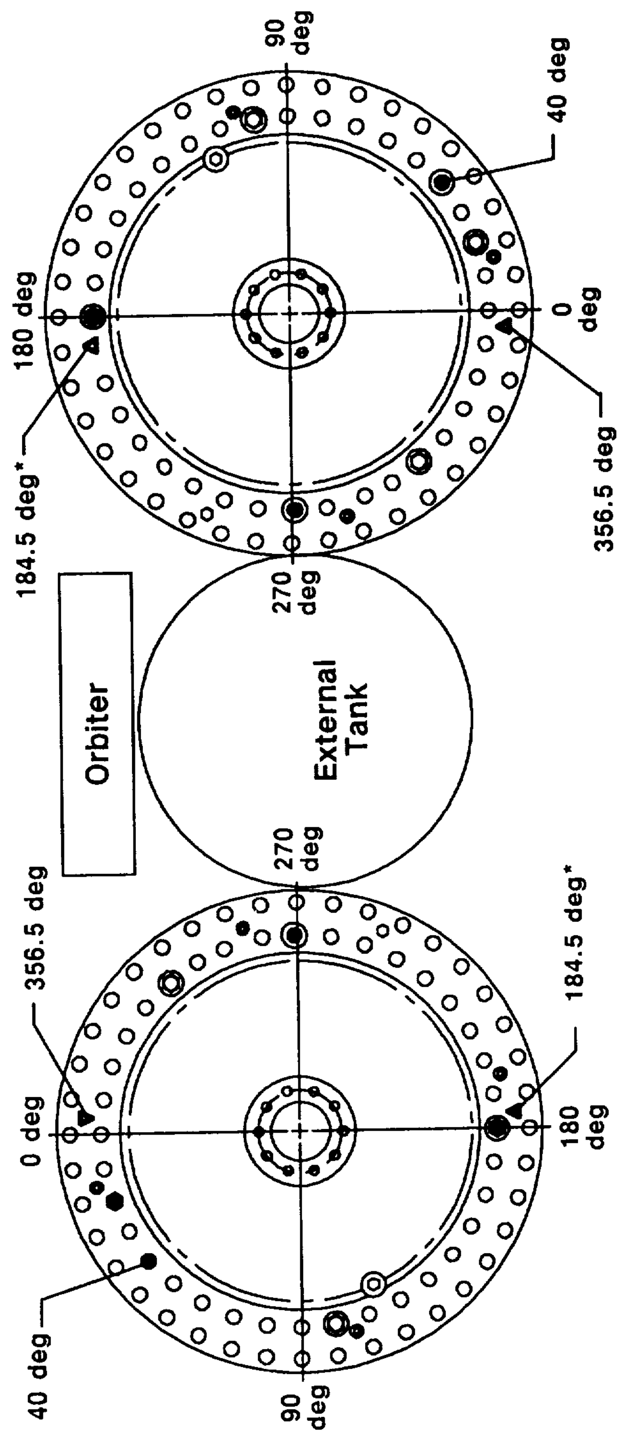

Legend
- △ GEI Temperature
- ● Pressure (OFI)

*One of two required for LCC compliance

Figure 4.8-6. Forward Dome GEI

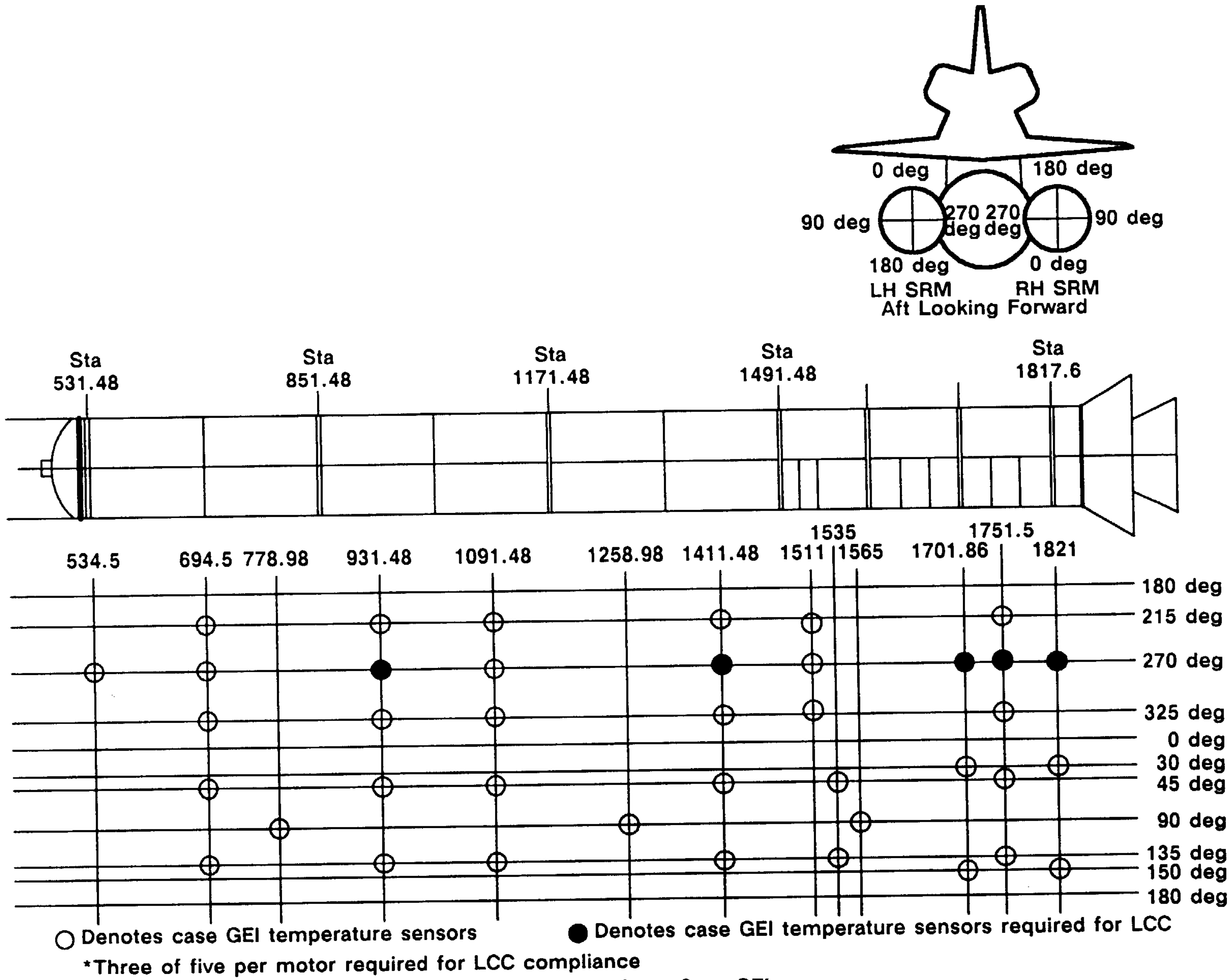

Figure 4.8-7. Case GEI

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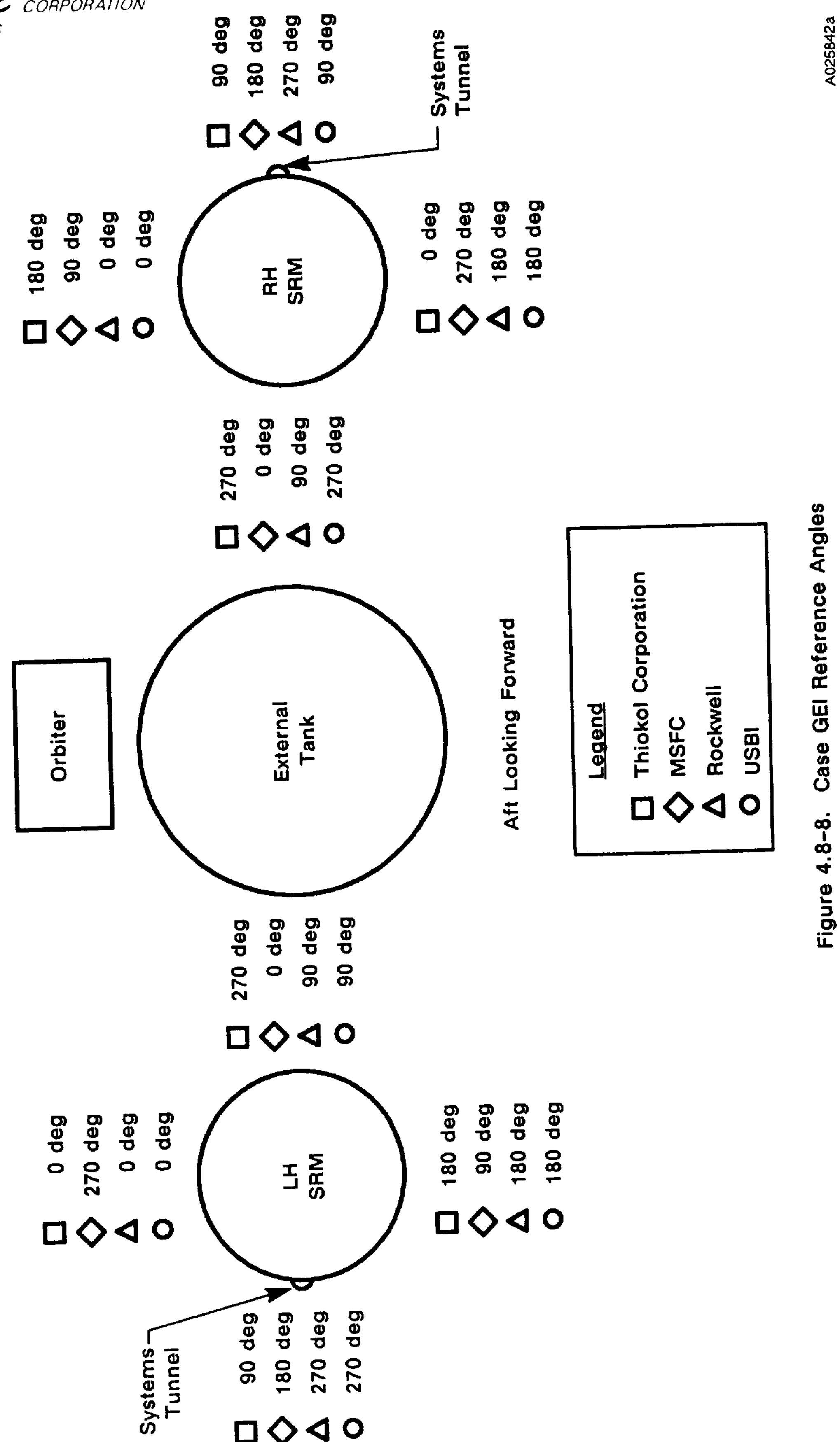
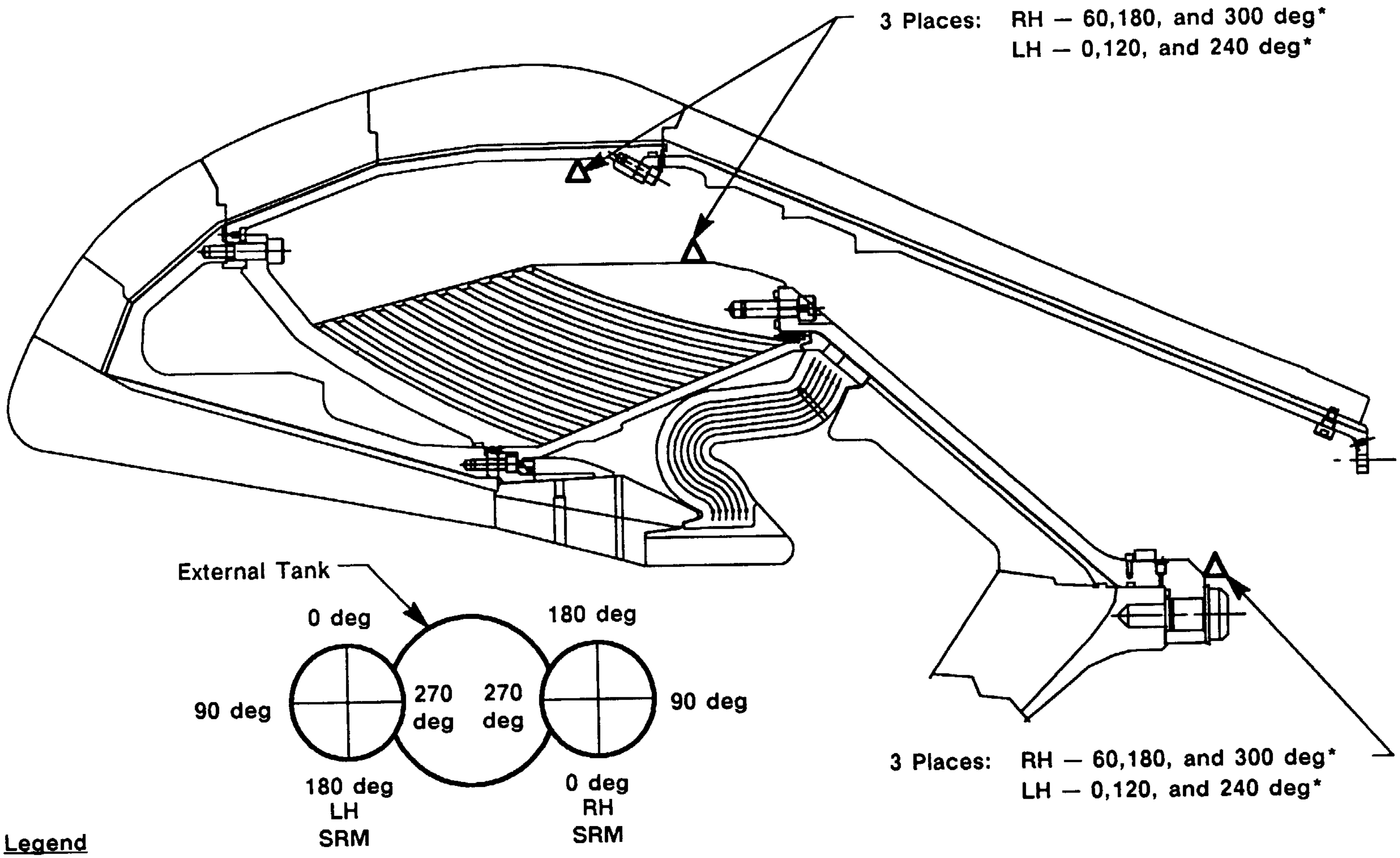


Figure 4.8-8. Case GEI Reference Angles



Legend

△ GEI Temperature
*Two of three per each location required for LCC compliance

Figure 4.8-9. Nozzle/Exit Cone GEI

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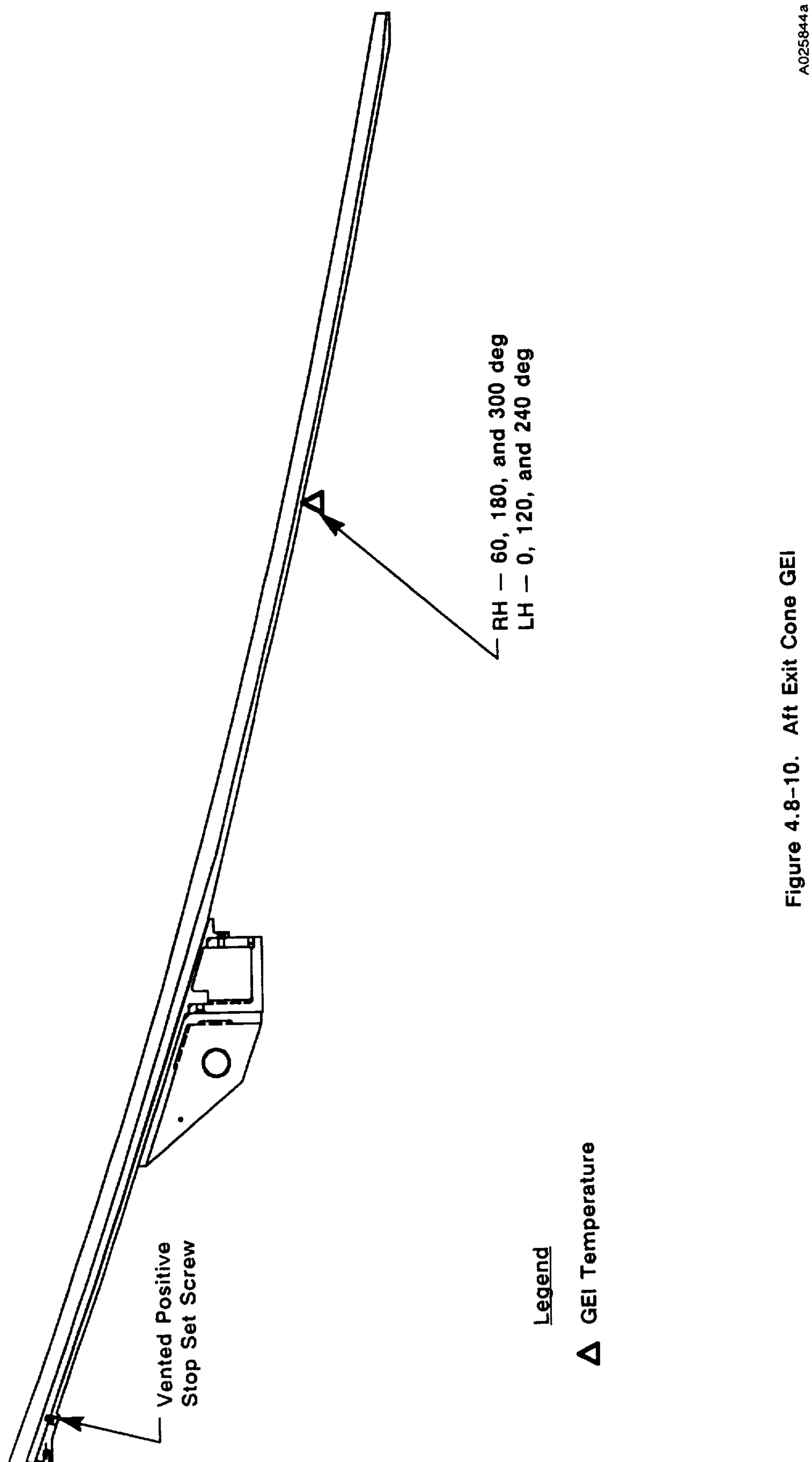

Figure 4.8-10. Aft Exit Cone GEI

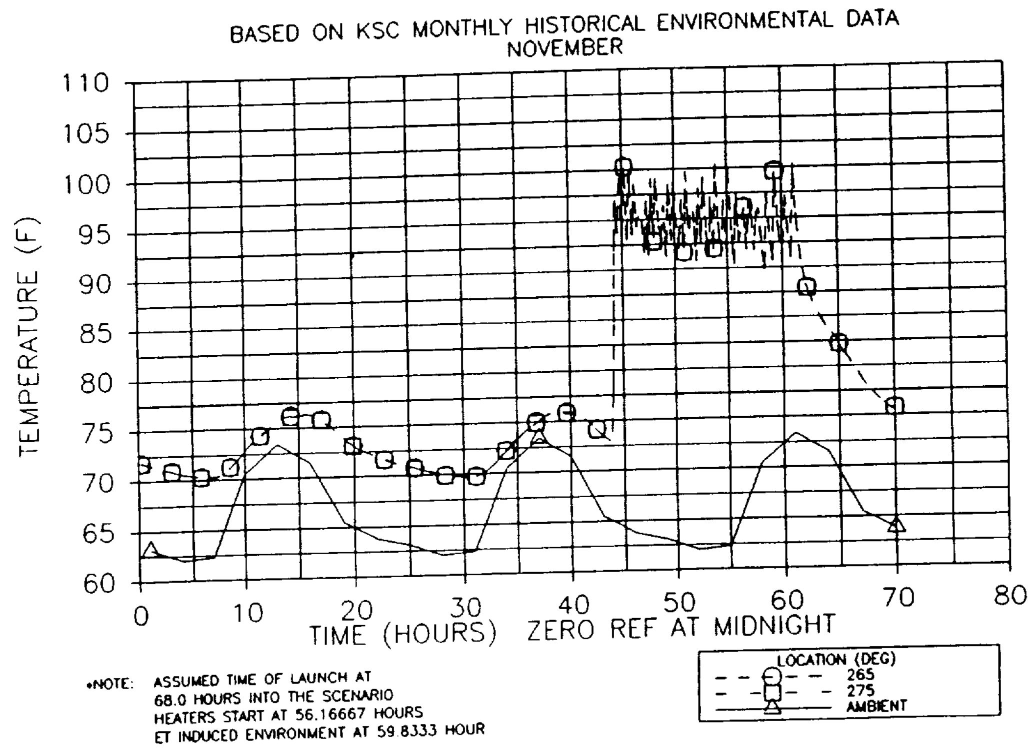

Figure 4.8-11. RH SRM Ignition System Region--Heater and GEI Sensor Temperature Prediction

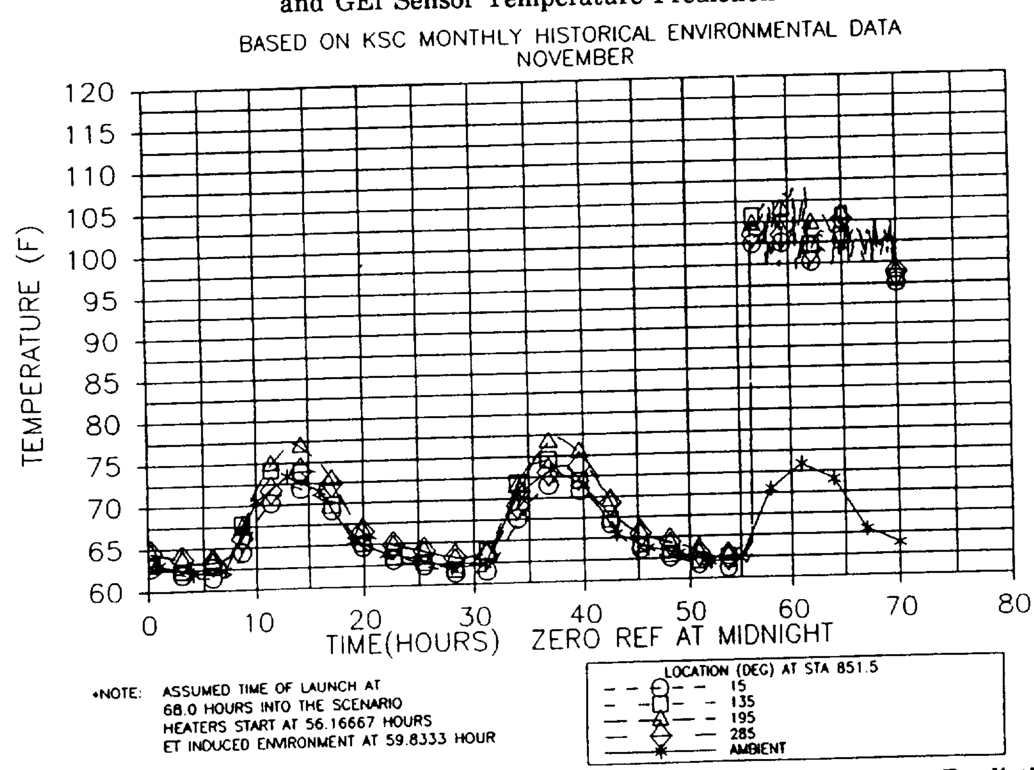

Figure 4.8-12. RH SRM Forward Field Joint--Heater Sensor Temperature Prediction

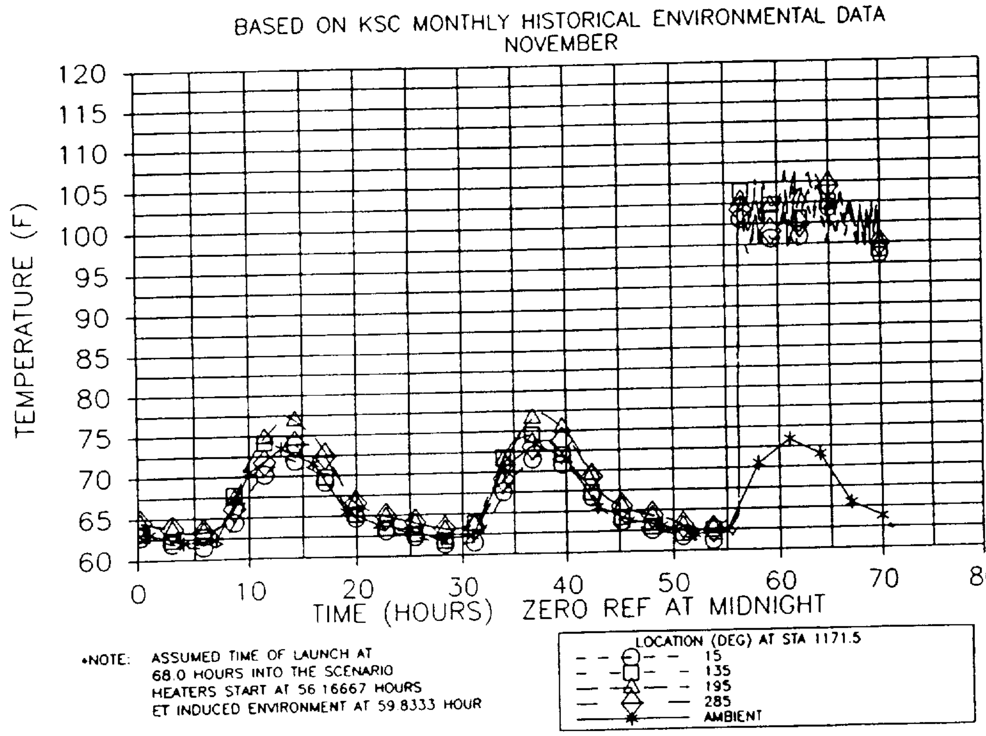

Figure 4.8-13. RH SRM Center Field Joint--Heater Sensor Temperature Prediction

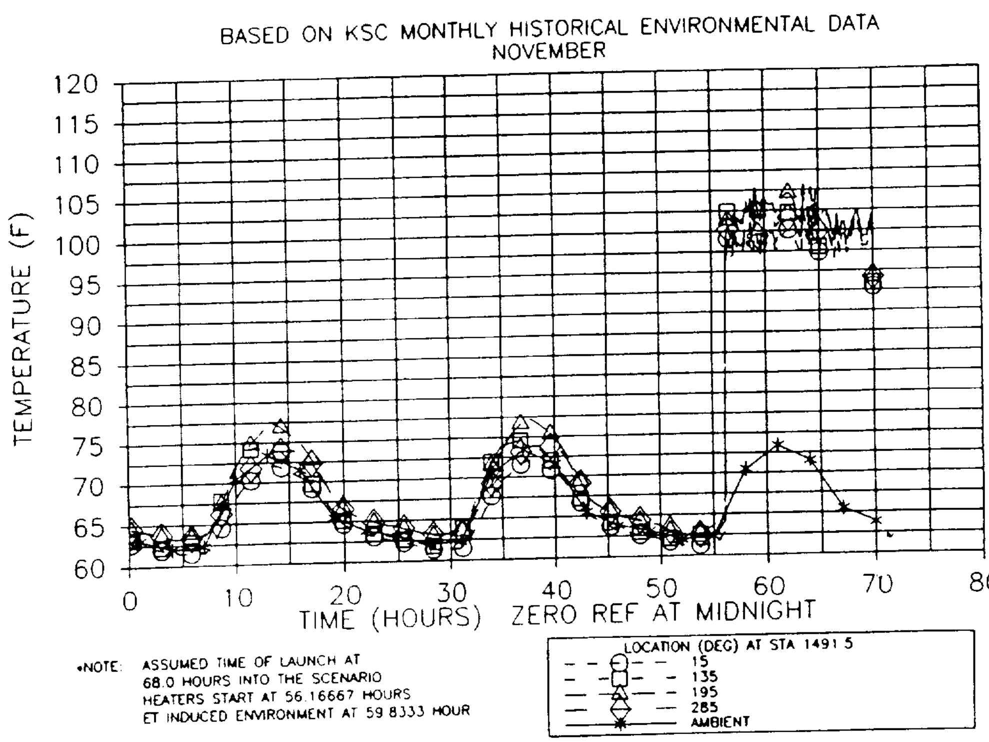

Figure 4.8-14. RH SRM Aft Field Joint--Heater Sensor Temperature Prediction

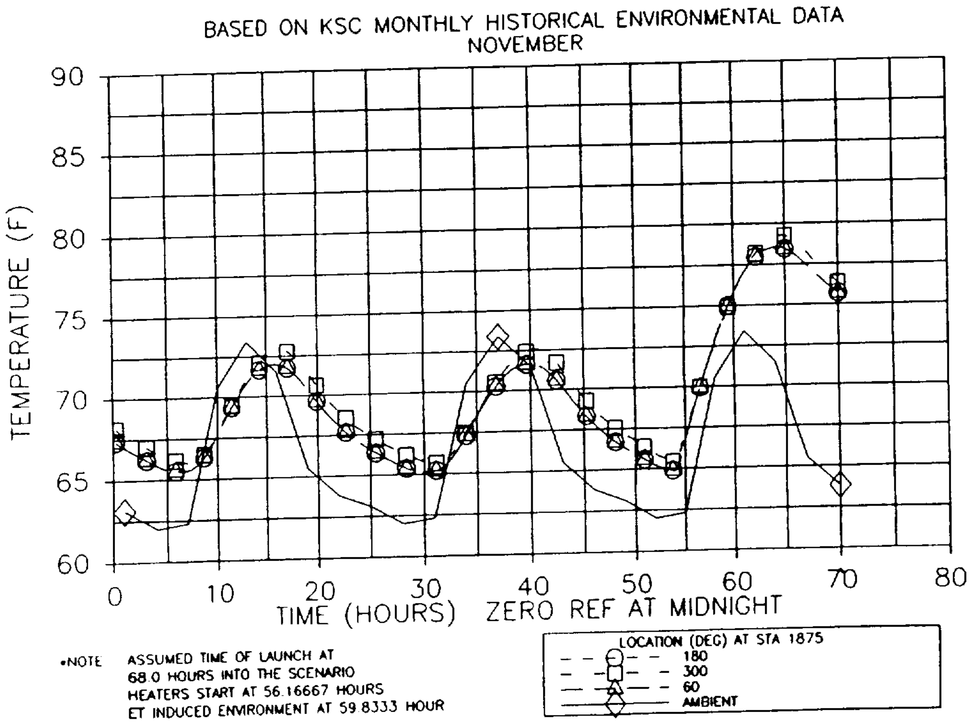

Figure 4.8-15. RH SRM Nozzle Region--GEI Sensor Temperature Prediction

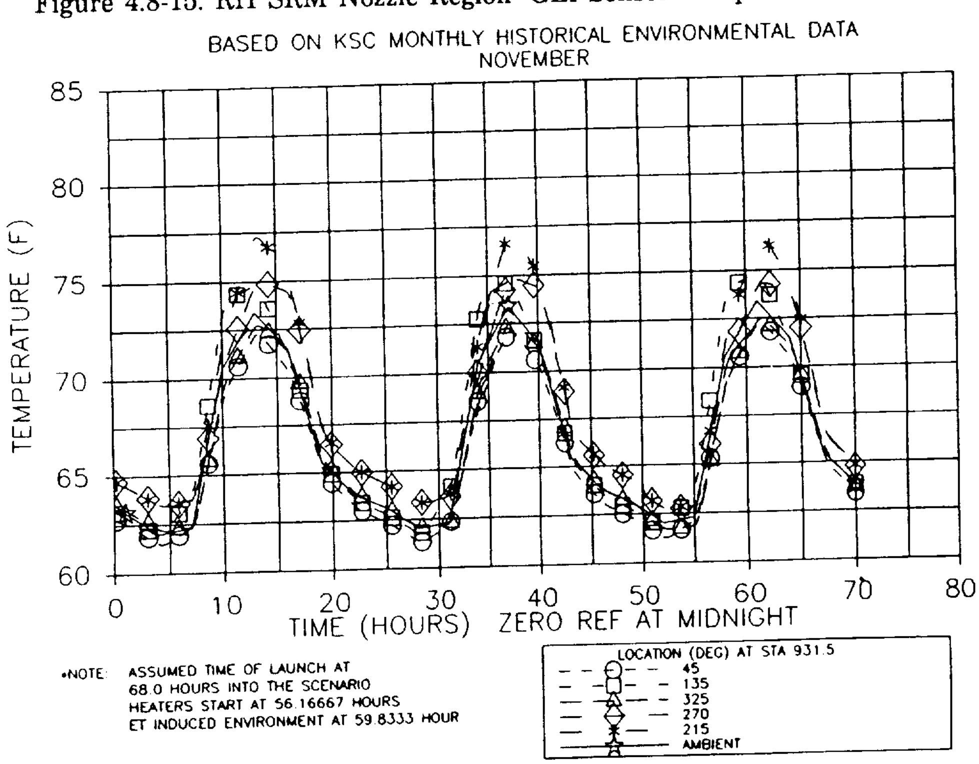

Figure 4.8-16. RH SRM Forward Case Acreage--GEI Sensor Temperature Prediction

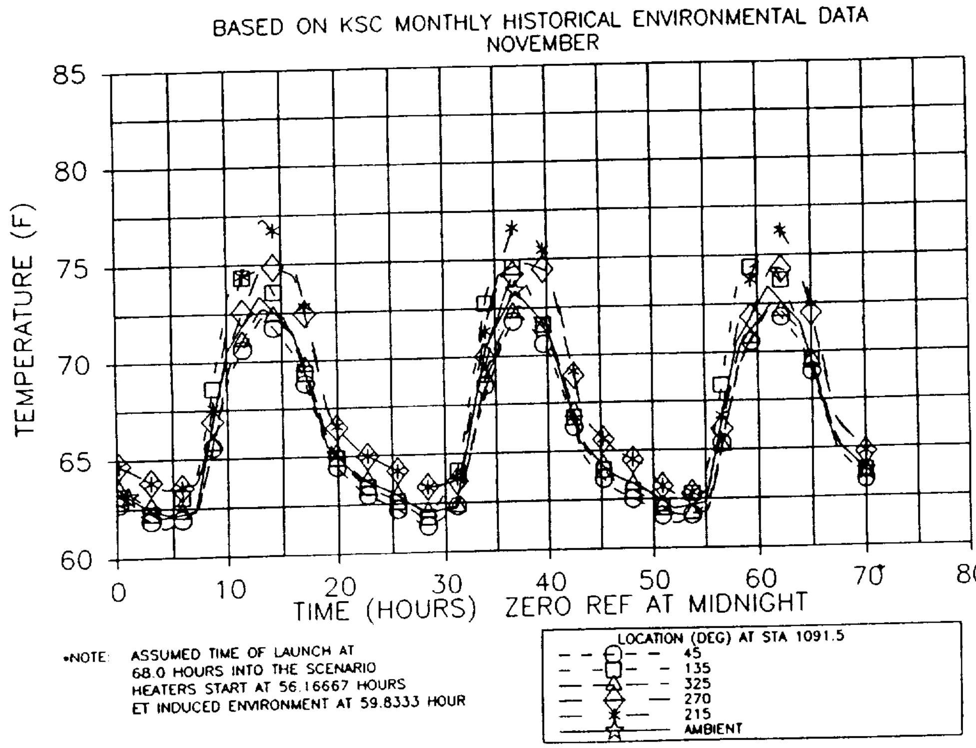

Figure 4.8-17. RH SRM Forward Center Case Acreage--GEI Sensor Temperature Prediction

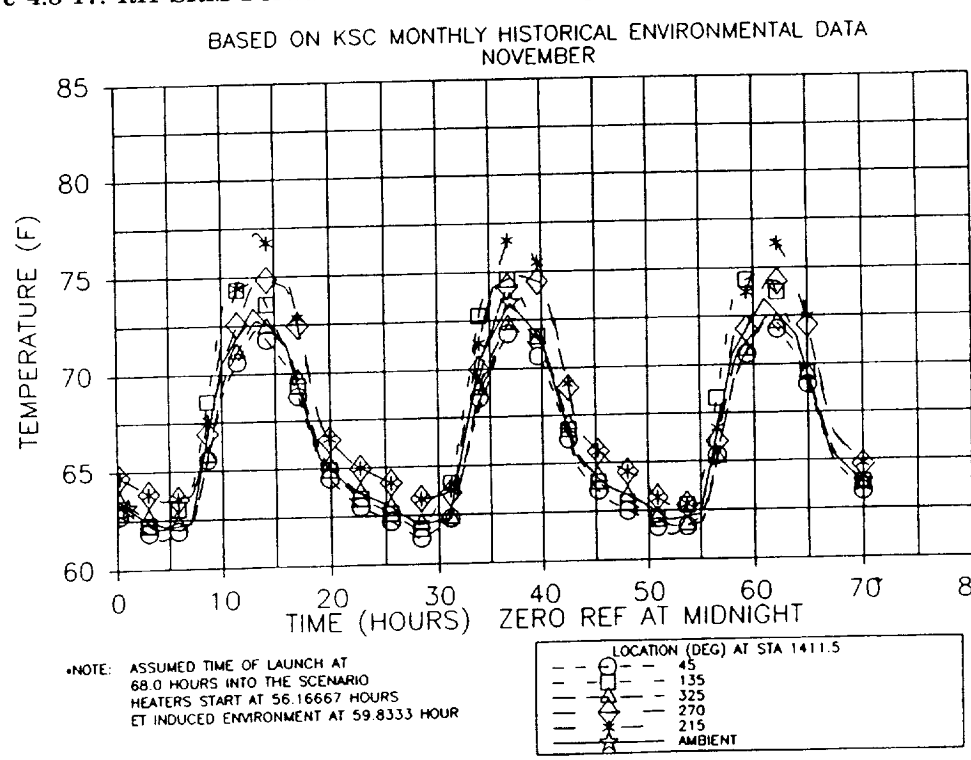

Figure 4.8-18. RH SRM Aft Center Case Acreage--GEI Sensor Temperature Prediction

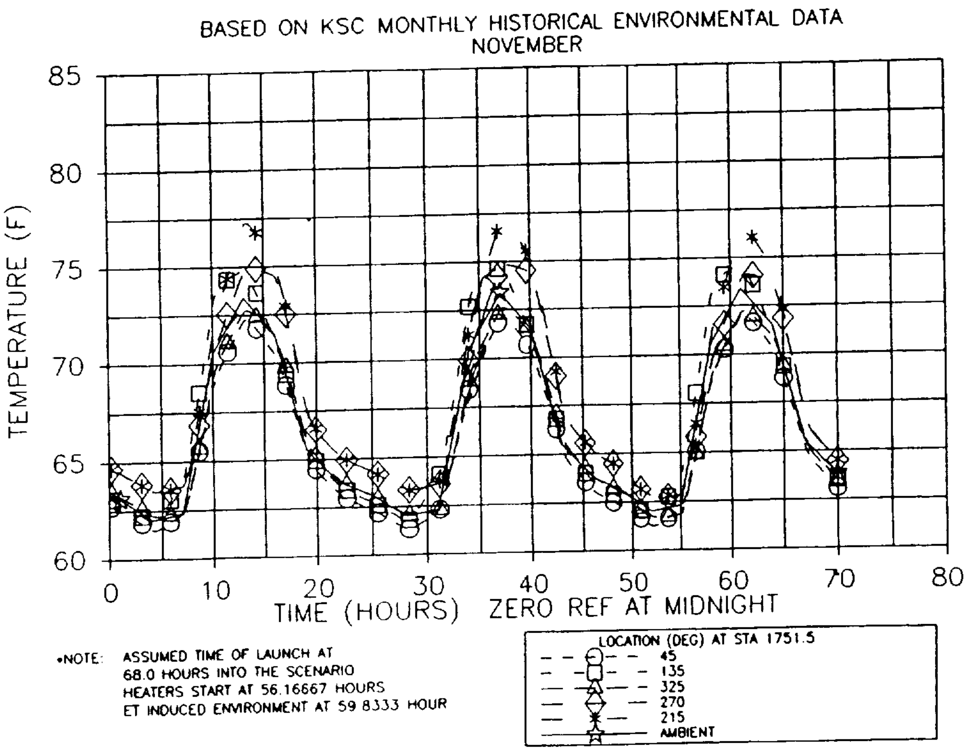

Figure 4.8-19. RH SRM Aft Case Acreage--GEI Sensor Temperature Prediction

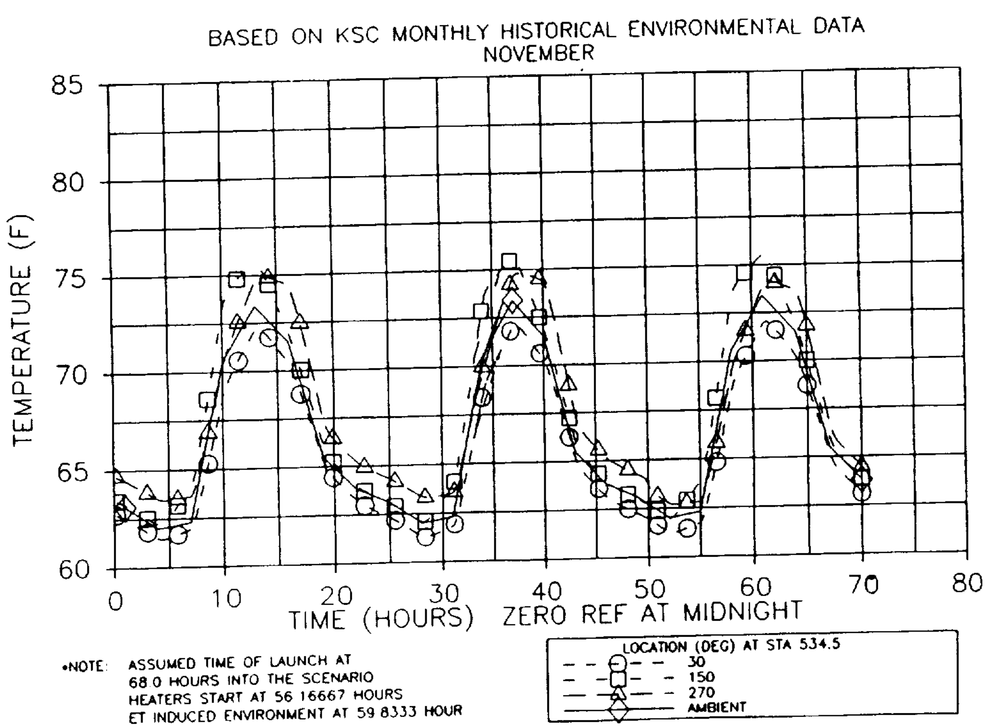

Figure 4.8-20. RH SRM Forward Dome Factory Joint--GEI Sensor Temperature Prediction

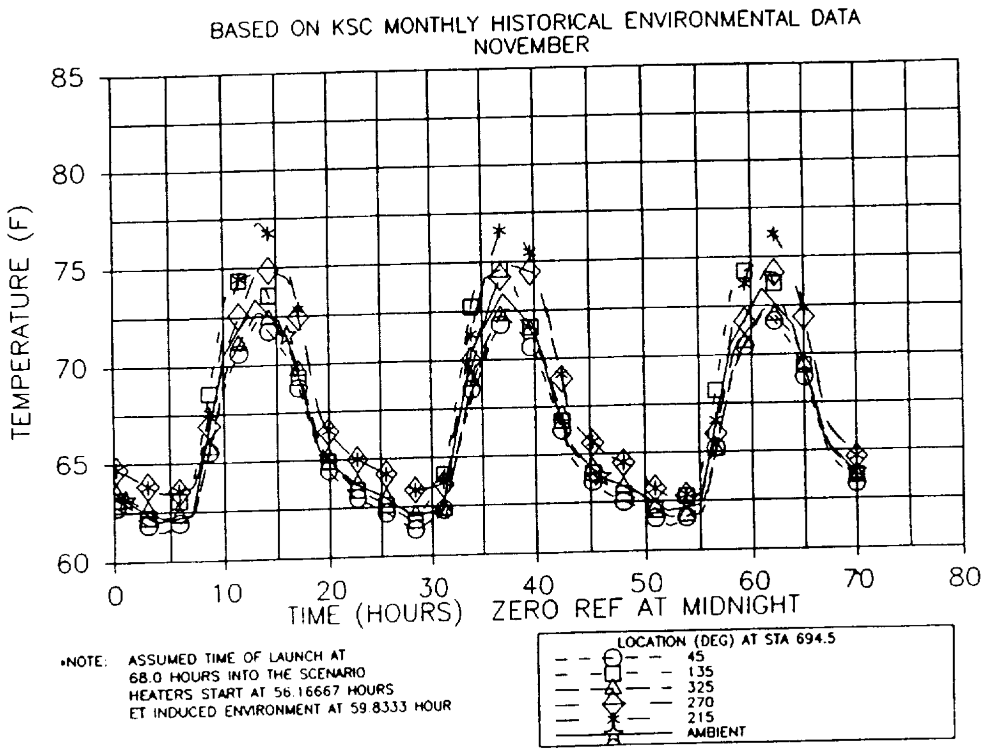

Figure 4.8-21. RH SRM Forward Factory Joint--GEI Sensor Temperature Prediction

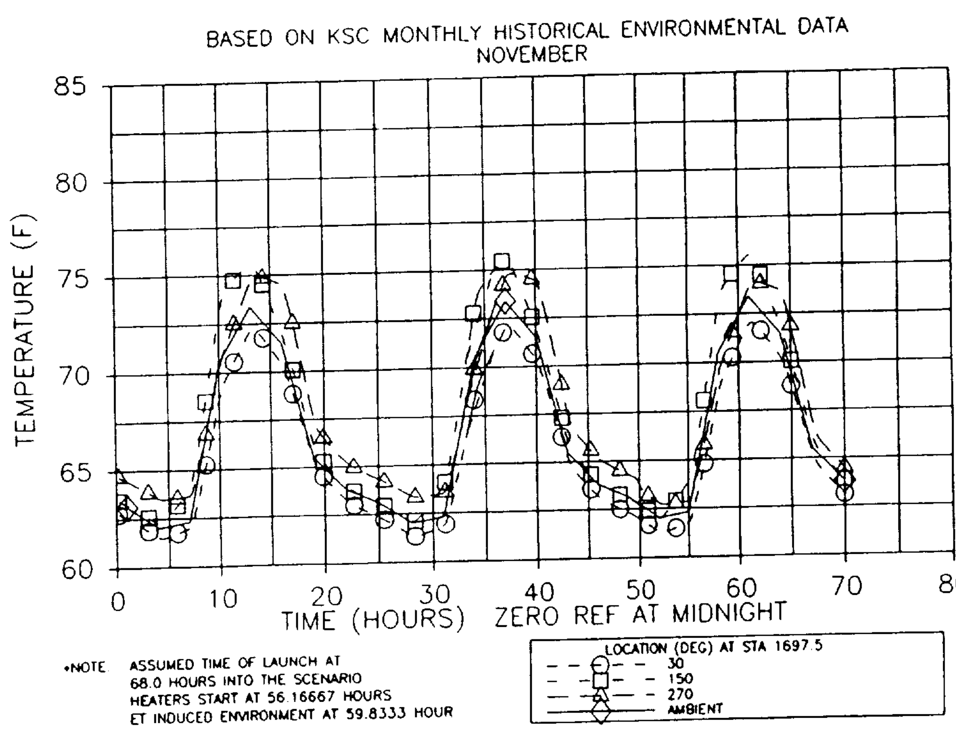

Figure 4.8-22. RH SRM Aft Factory Joint--GEI Sensor Temperature Prediction

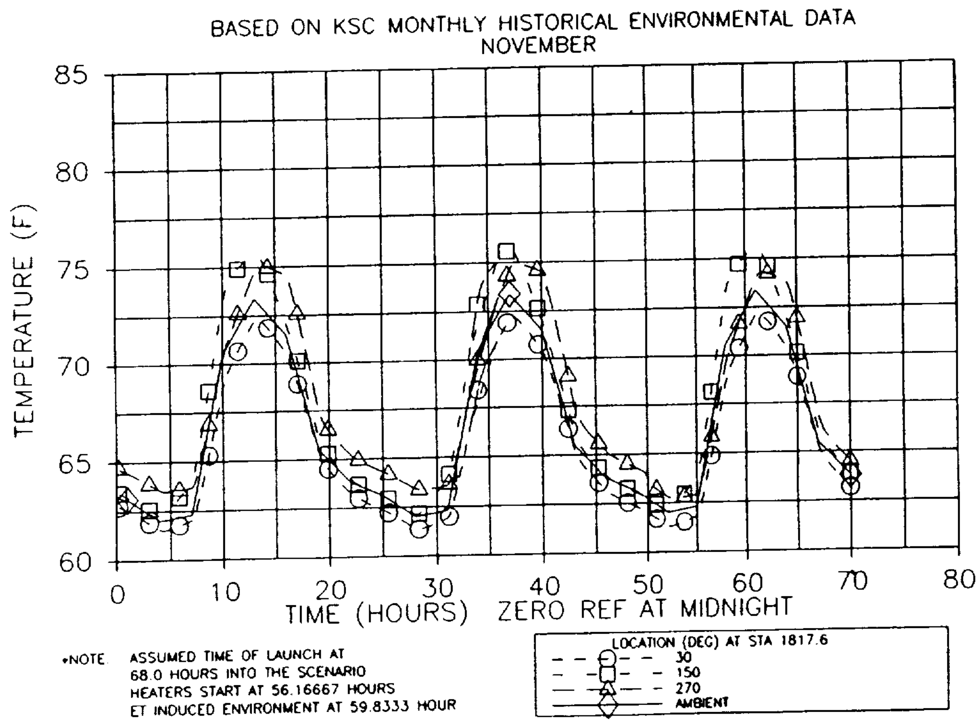

Figure 4.8-23. RH SRM Aft Dome Factory Joint--GEI Sensor Temperature Prediction

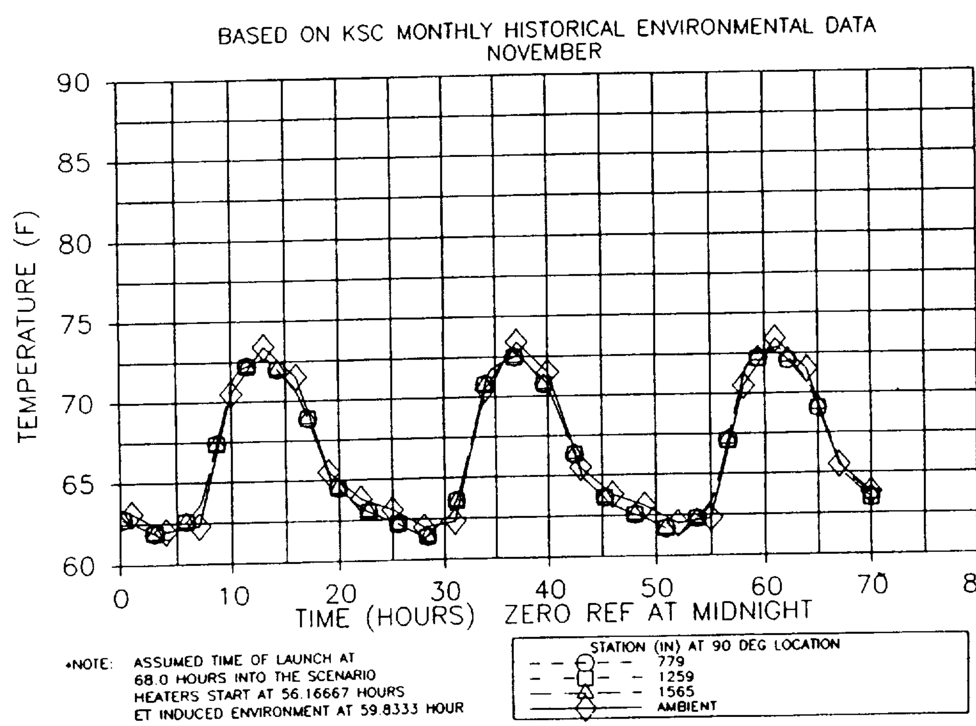

Figure 4.8-24. RH SRM Tunnel Bondline--GEI Sensor Temperature Prediction

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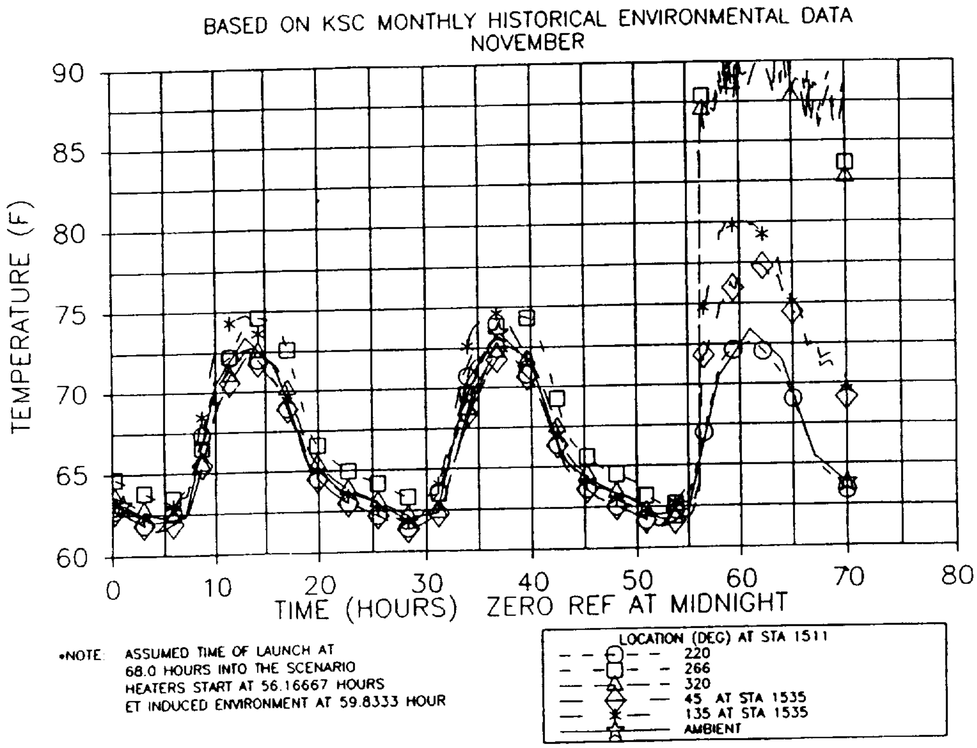
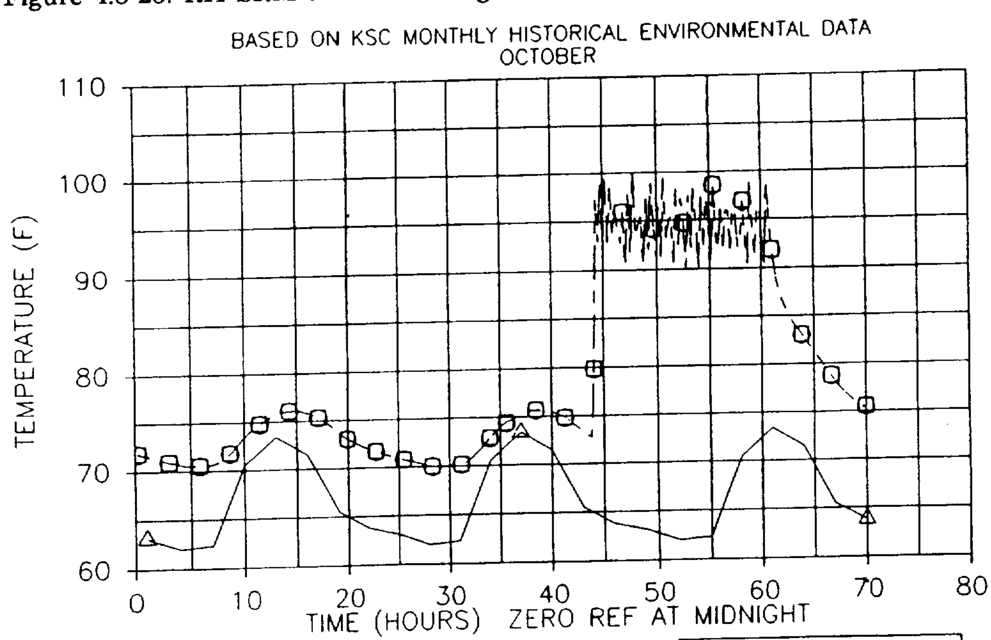


•NOTE: ASSUMED TIME OF LAUNCH AT 68.0 HOURS INTO THE SCENARIO
HEATERS START AT 56.16667 HOURS
ET INDUCED ENVIRONMENT AT 59.8333 HOUR

Figure 4.8-25. RH SRM ET Attach Region--GEI Sensor Temperature Prediction



•NOTE: ASSUMED TIME OF LAUNCH AT 68.0 HOURS INTO THE SCENARIO
HEATERS START AT 56.16667 HOURS
ET INDUCED ENVIRONMENT AT 59.8333 HOUR

Figure 4.8-26. LH SRM Ignition System Region--Heater and GEI Sensor Temperature Prediction

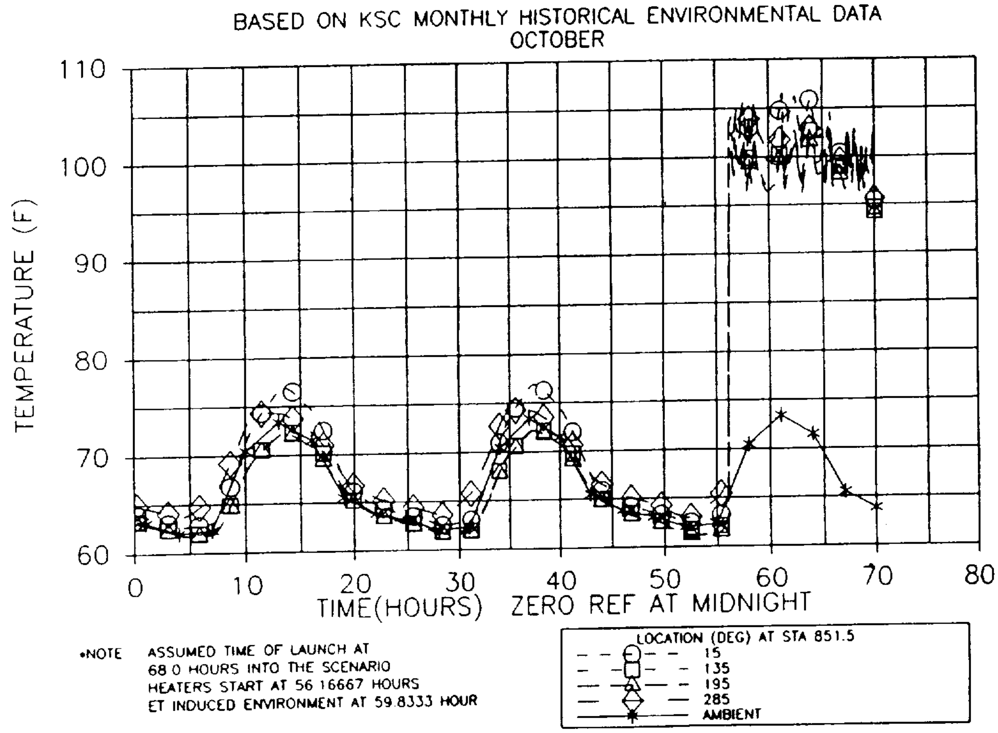


Figure 4.8-27. LH SRM Forward Field Joint--Heater Sensor Temperature Prediction

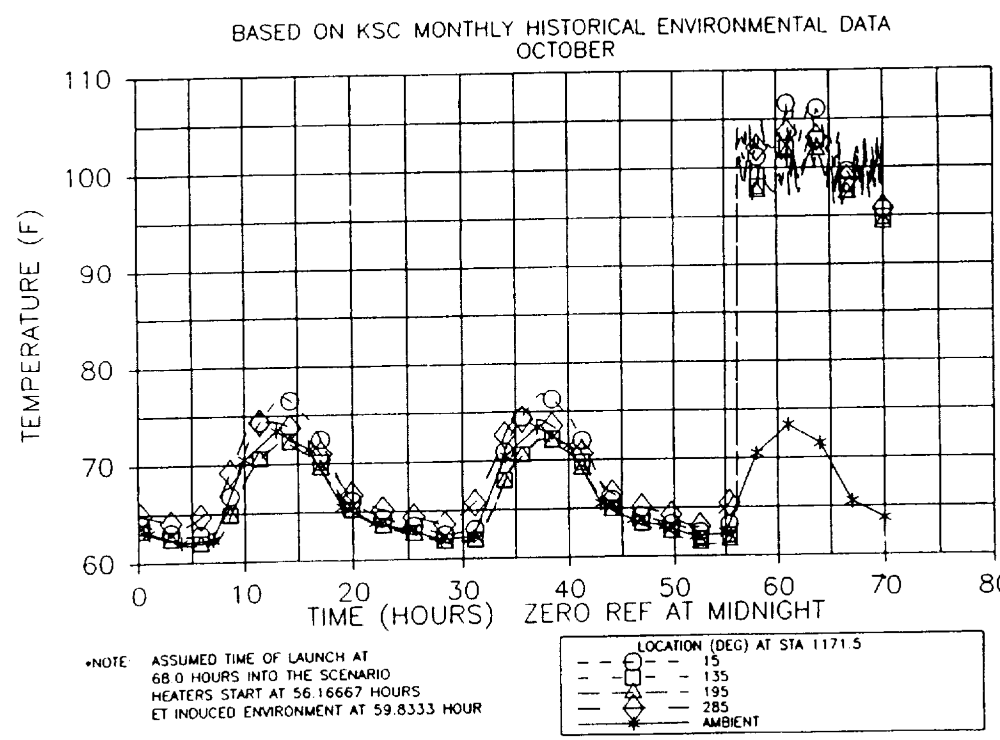


Figure 4.8-28. LH SRM Center Field Joint--Heater Sensor Temperature Prediction

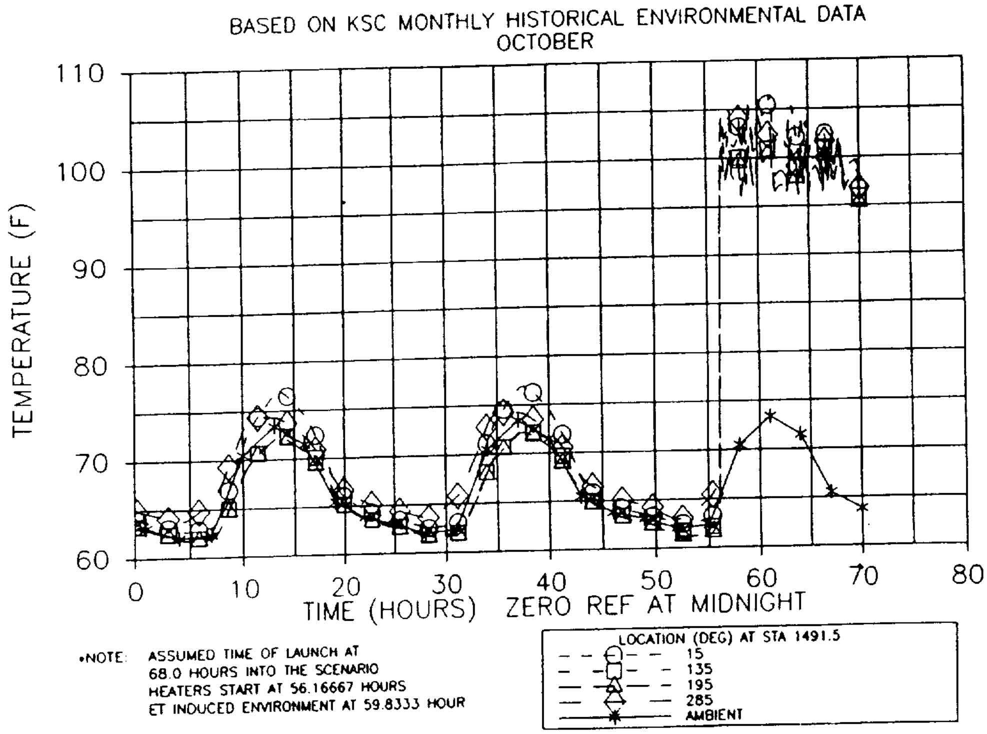


Figure 4.8-29. LH SRM Aft Field Joint--Heater Sensor Temperature Prediction

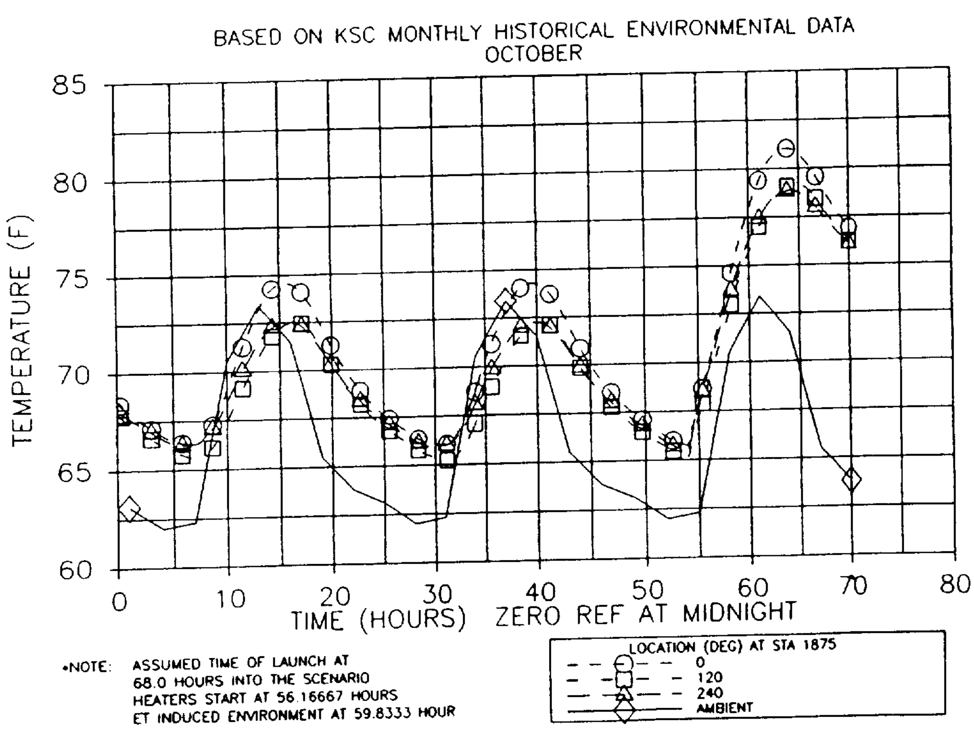


Figure 4.8-30. LH SRM Nozzle Region--GEI Sensor Temperature Prediction

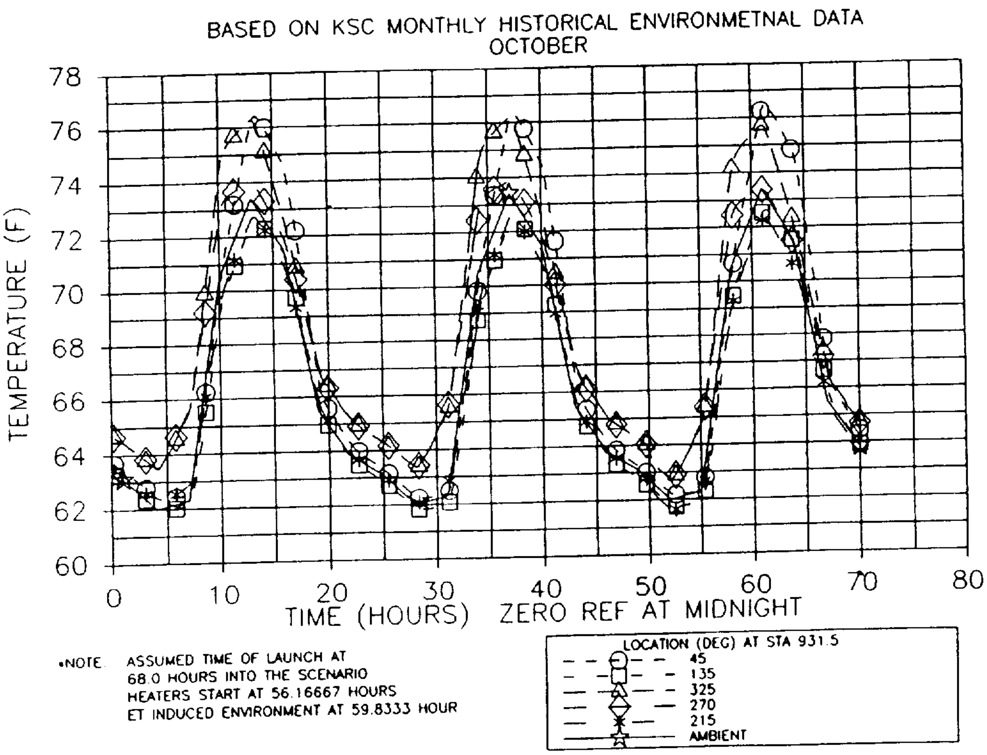


Figure 4.8-31. LH SRM Forward Case Acreage--GEI Sensor Temperature Prediction

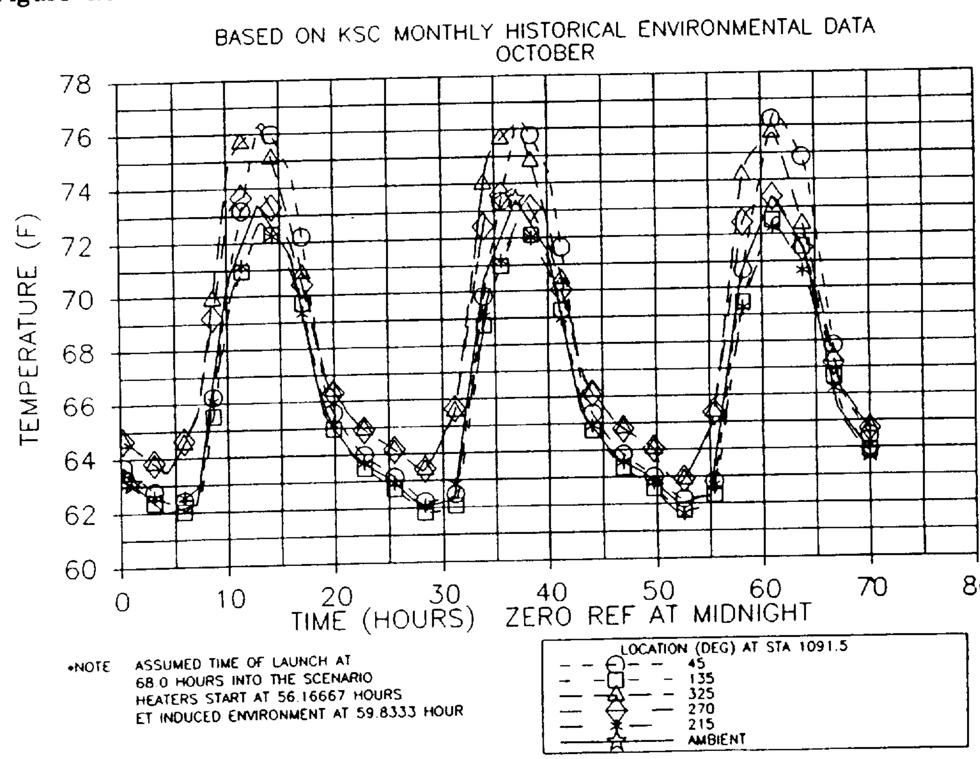


Figure 4.8-32. LH SRM Forward Center Case Acreage--
GEI Sensor Temperature Prediction

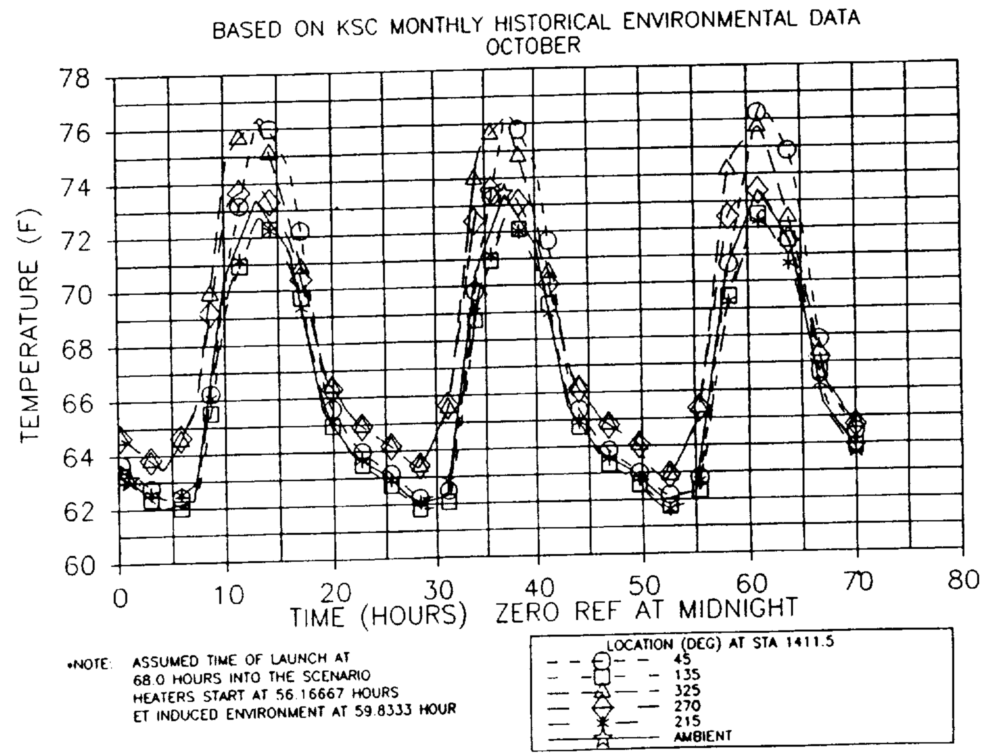


Figure 4.8-33. LH SRM Aft Center Case Acreage--GEI Sensor Temperature Prediction

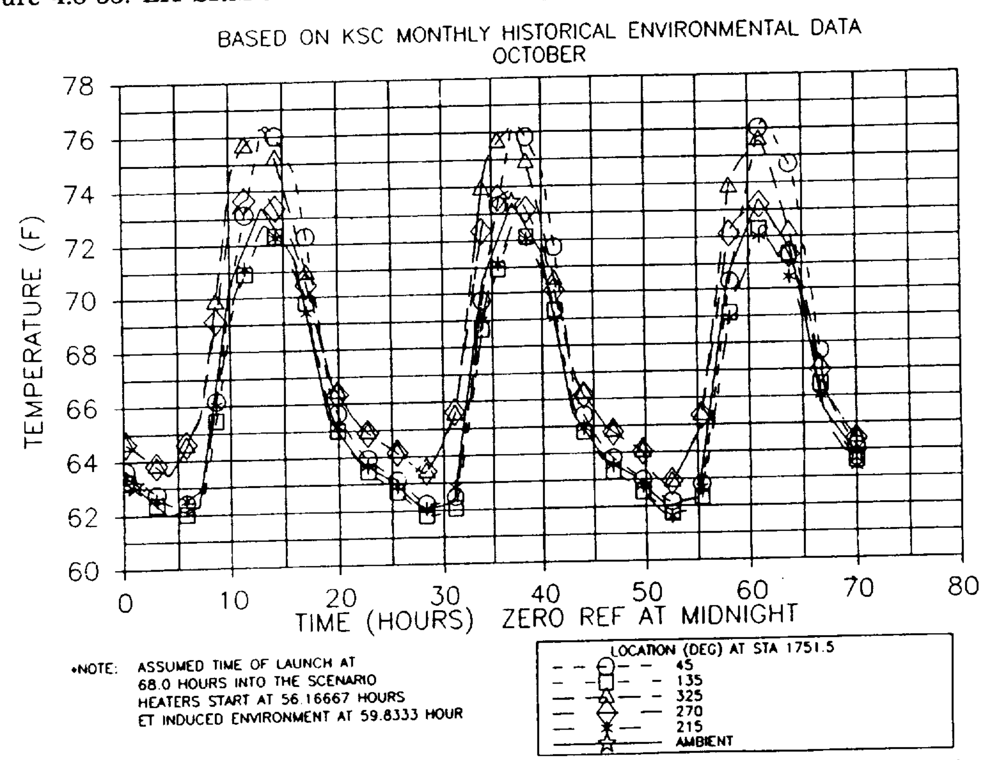


Figure 4.8-34. LH SRM Aft Case Acreage--GEI Sensor Temperature Prediction

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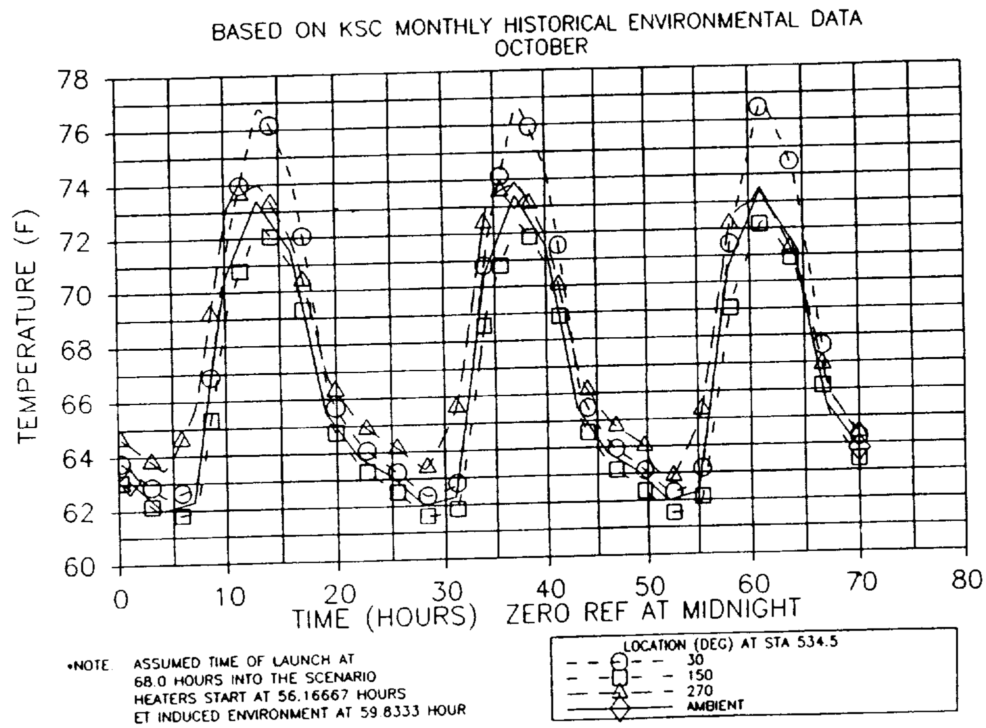

Figure 4.8-35. LH SRM Forward Dome Factory Joint--GEI Sensor Temperature Prediction

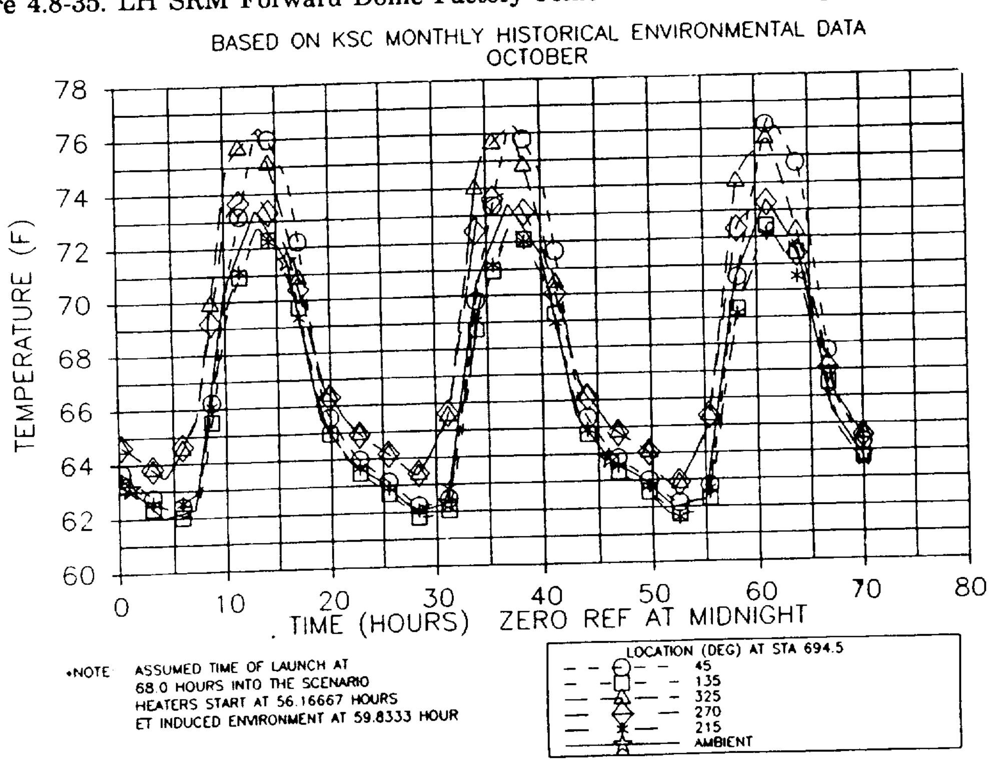

Figure 4.8-36. LH SRM Forward Factory Joint--GEI Sensor Temperature Prediction

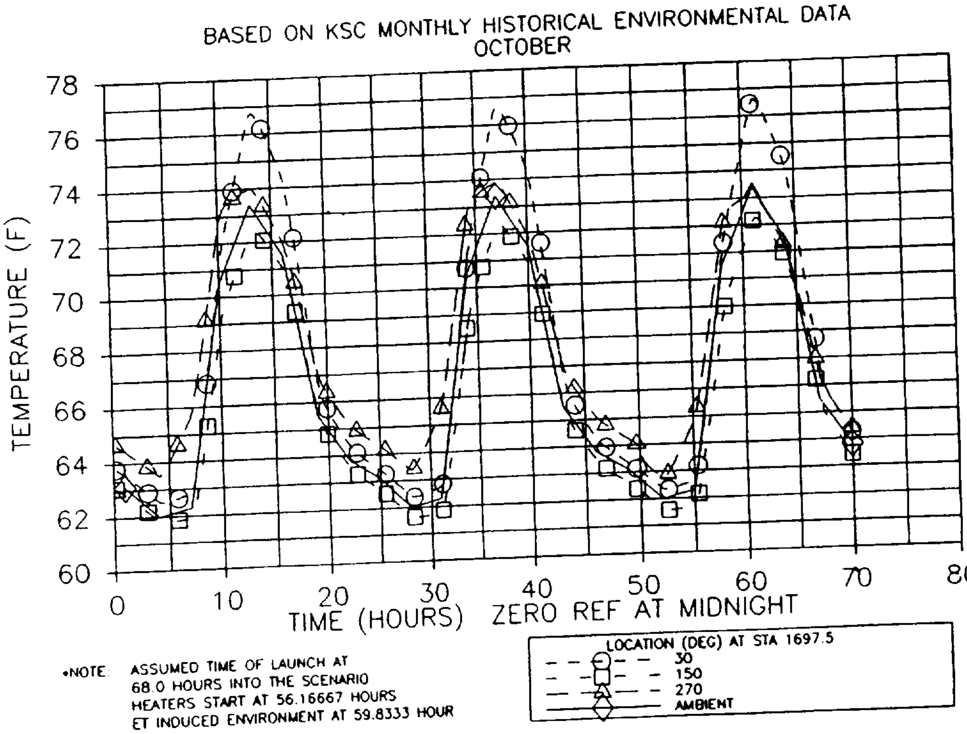

Figure 4.8-37. LH SRM Aft Factory Joint--GEI Sensor Temperature Prediction

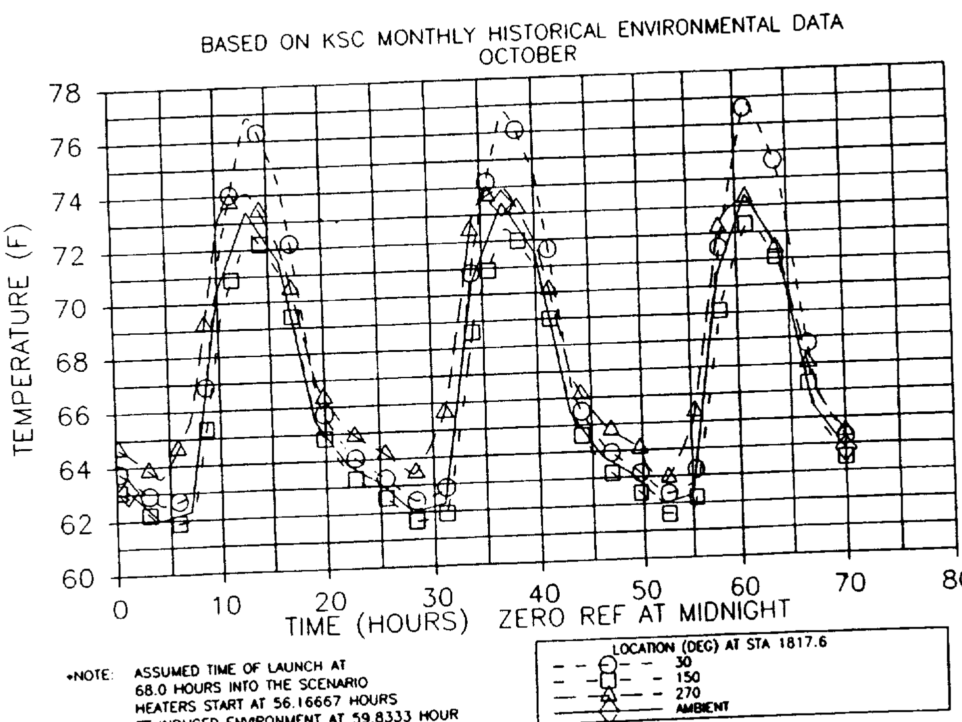

Figure 4.8-38. LH SRM Aft Dome Factory Joint--GEI Sensor Temperature Prediction

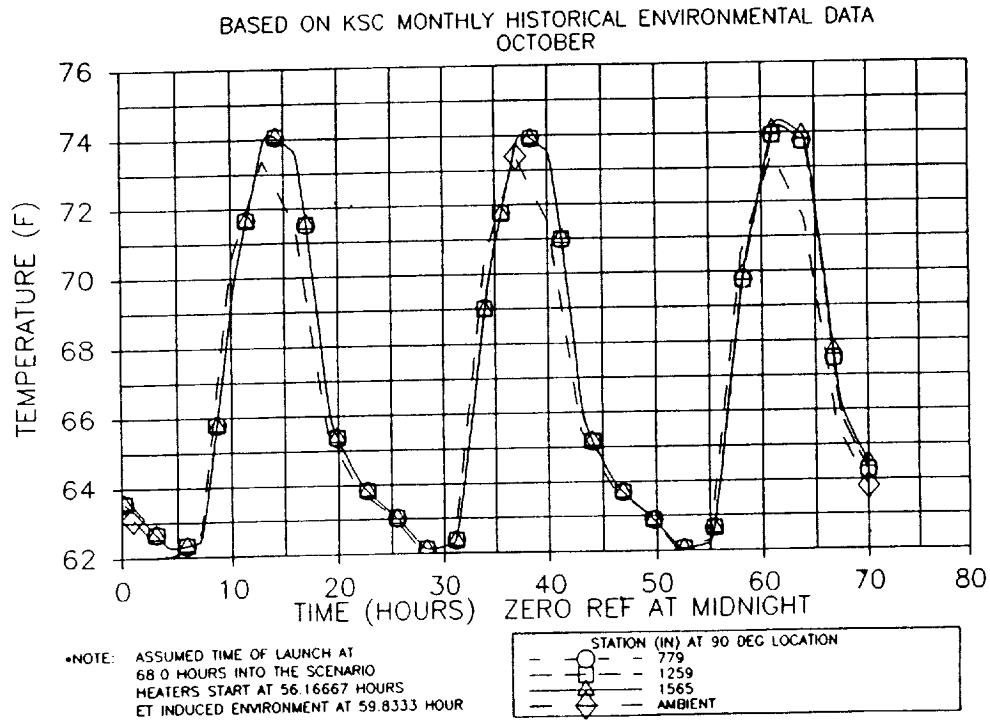

Figure 4.8-39. LH SRM Systems Tunnel Bondline--GEI Sensor Temperature Prediction

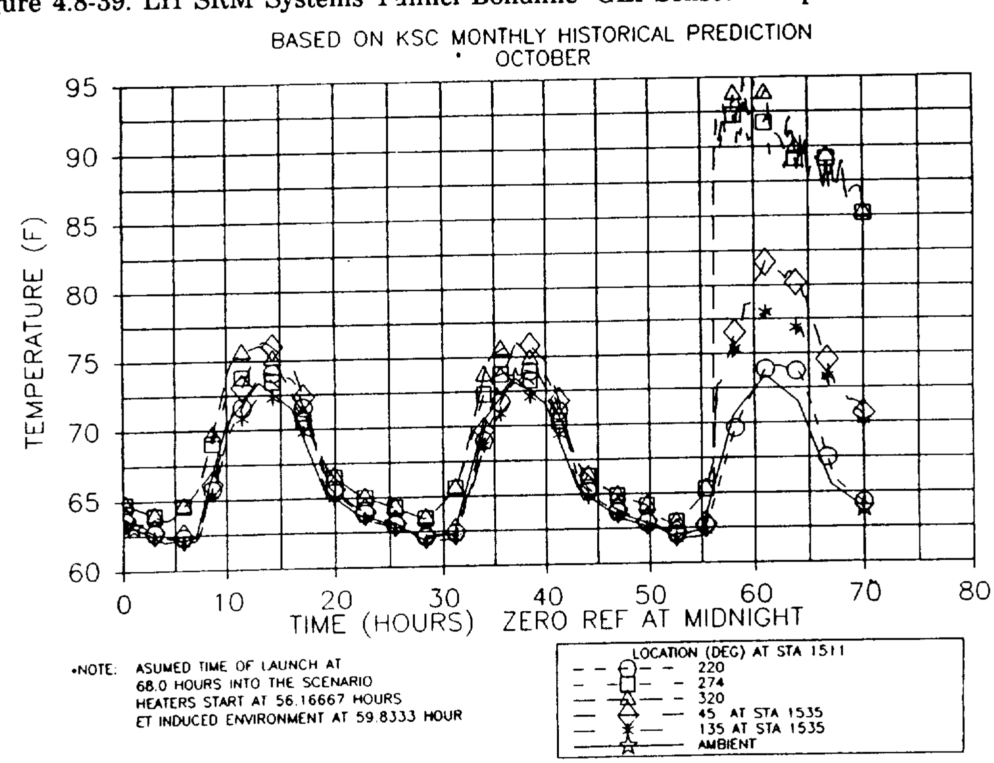

Figure 4.8-40. LH SRM ET Attach Region--GEI Sensor Temperature Prediction

Table 4.8-6. STS-33R Analytical Timeframes for Estimating Event Sequencing of November Historical Joint Heater and GEI Sensor Predictions

Time (hr)	Countdown Events in Analysis
0:01	12:01 a.m. KSC EST (20 Nov 1989)
44:00	Igniter joint heater operation begins on 21 Nov 1989 (L-24 hr)
54:10	Aft skirt conditioning oepration begins on 22 Nov 1989 (T-13 hr, 50 min)
56:10	Field joint heater operation begins on 22 Nov 1989 (L-11 hr, 50 min)
59:00	Induced environments due to ET refrigeration effects begins on 22 Nov 1989 (approximately L-9 hr)
61:10	Igniter heater shutoff/start cooldown on 22 Nov 1989 (L-6 hr, 50 min)
68:00	Assumed time of Launch 22 Nov 1989, 8:00 p.m. KSC EST

Note: Figures 4.8-11 through 4.8-40 consist of a 2-day plus 22-hr scenario

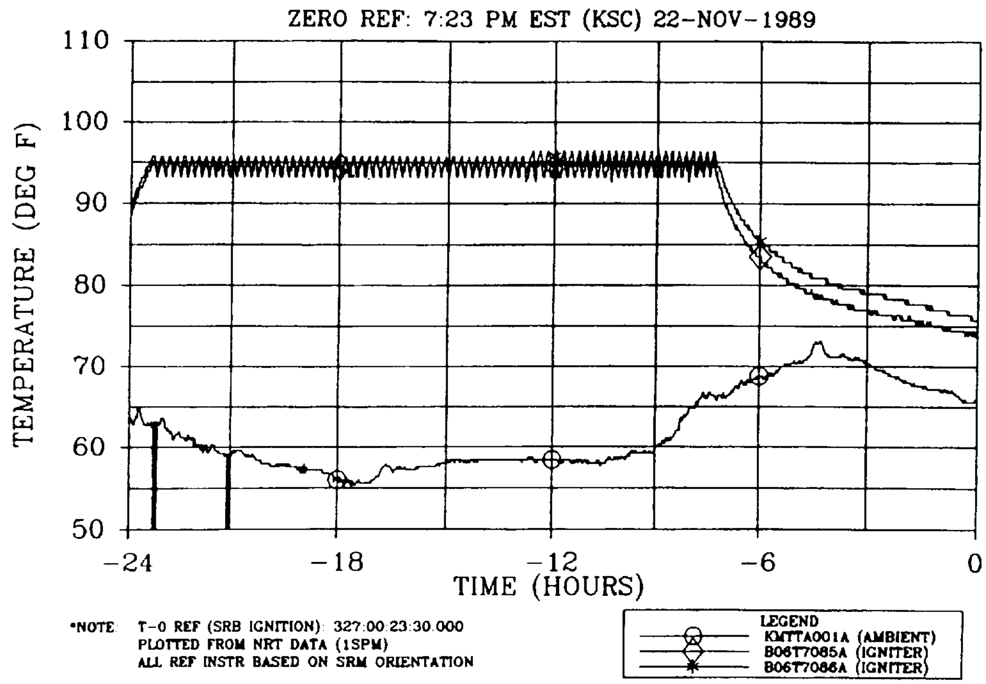

Figure 4.8-41. LH SRM Igniter Joint Temperatures (overlaid with ambient)

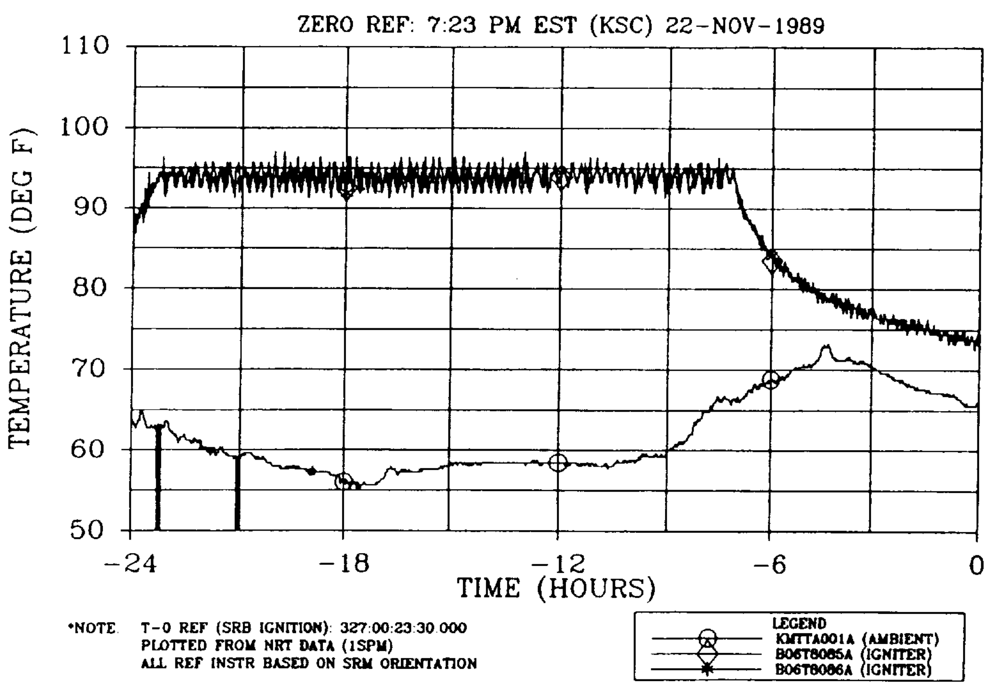

Figure 4.8-42. RH SRM Igniter Joint Temperature (overlaid with ambient)

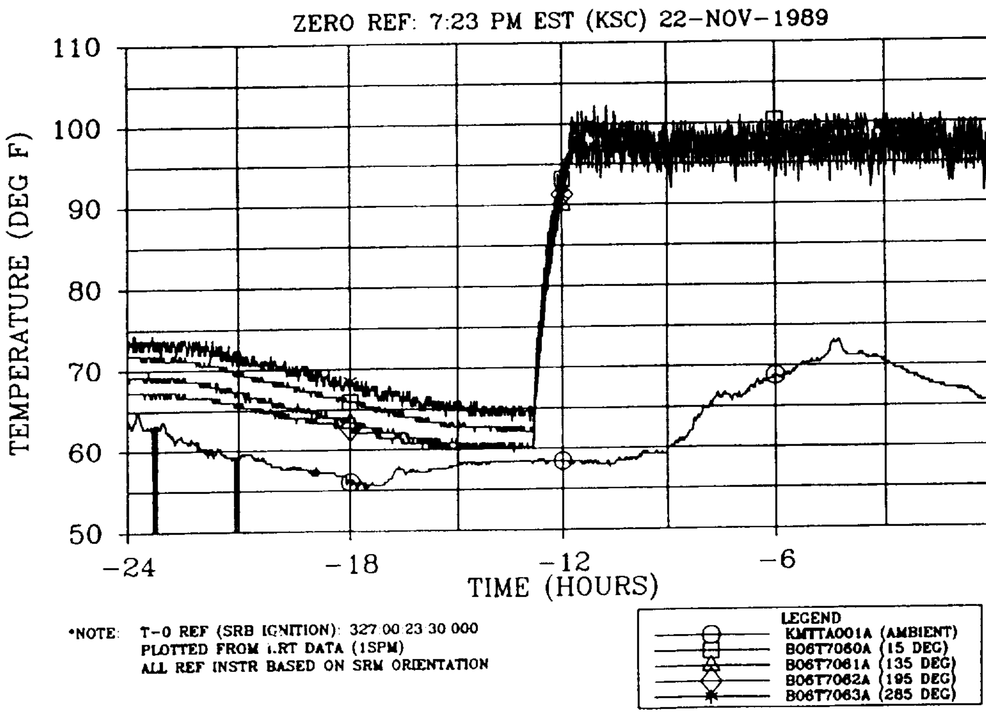

Figure 4.8-43. LH SRM Forward Field Joint Temperature (overlaid with ambient)

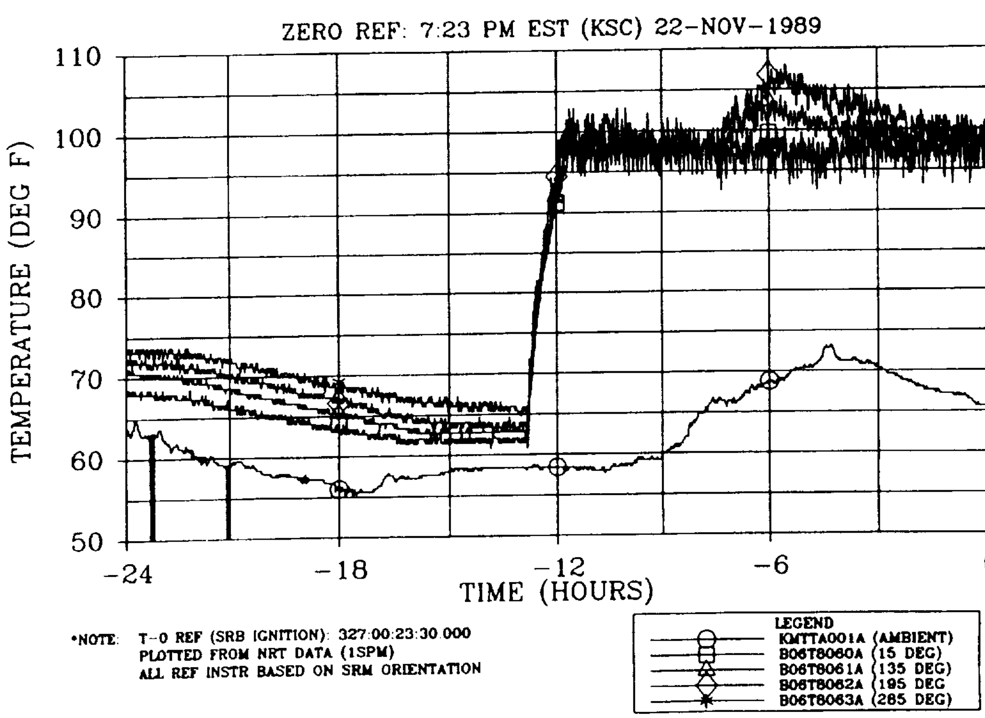

Figure 4.8-44. RH SRM Forward Field Joint Temperature (overlaid with ambient)

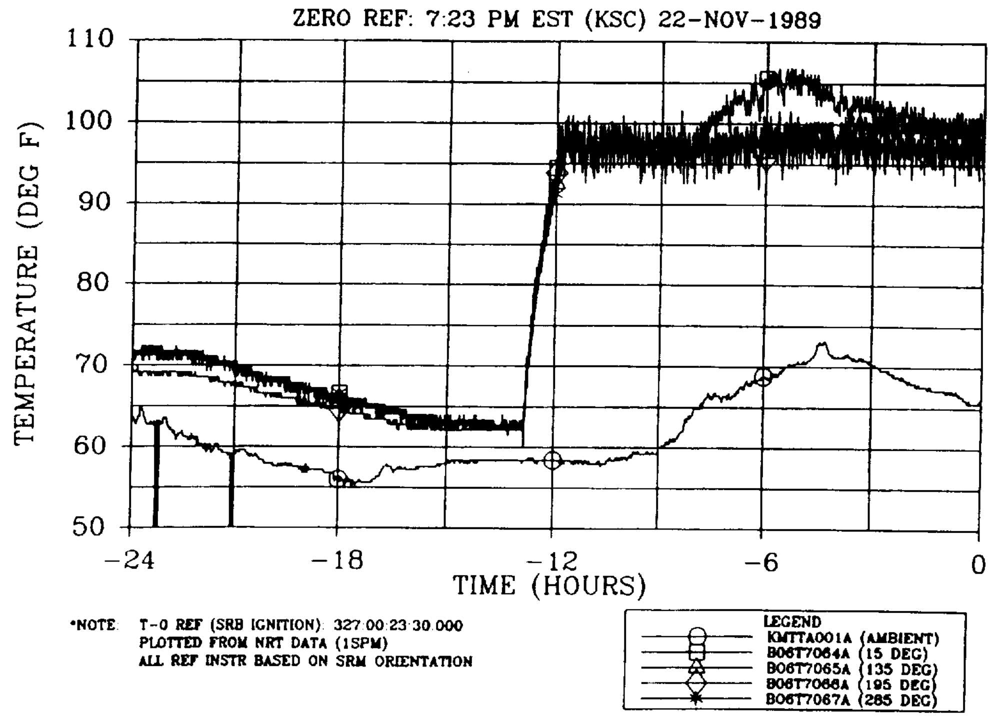

Figure 4.8-45. LH SRM Center Field Joint Temperature (overlaid with ambient)

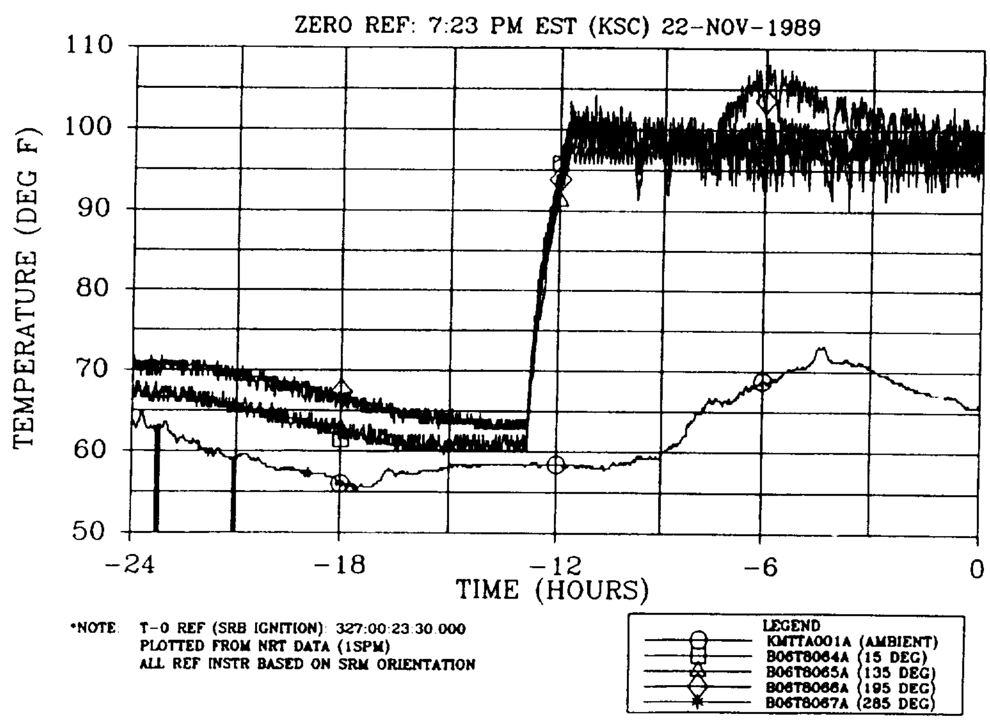

Figure 4.8-46. RH SRM Center Field Joint Temperature (overlaid with ambient)

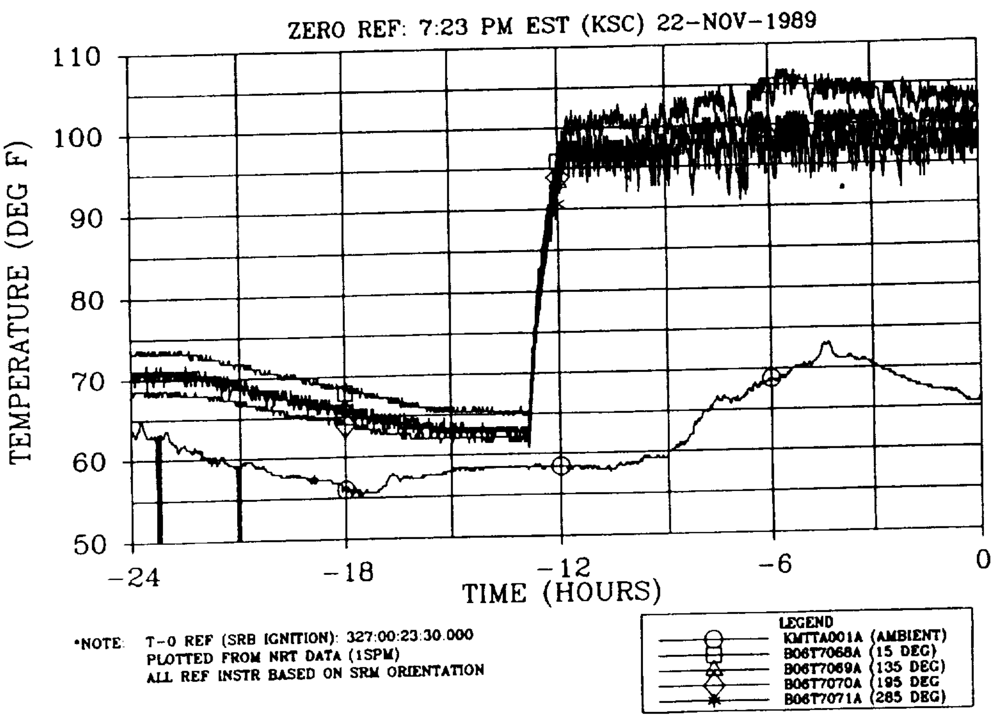

Figure 4.8-47. LH SRM Aft Field Joint Temperature (overlaid with ambient)

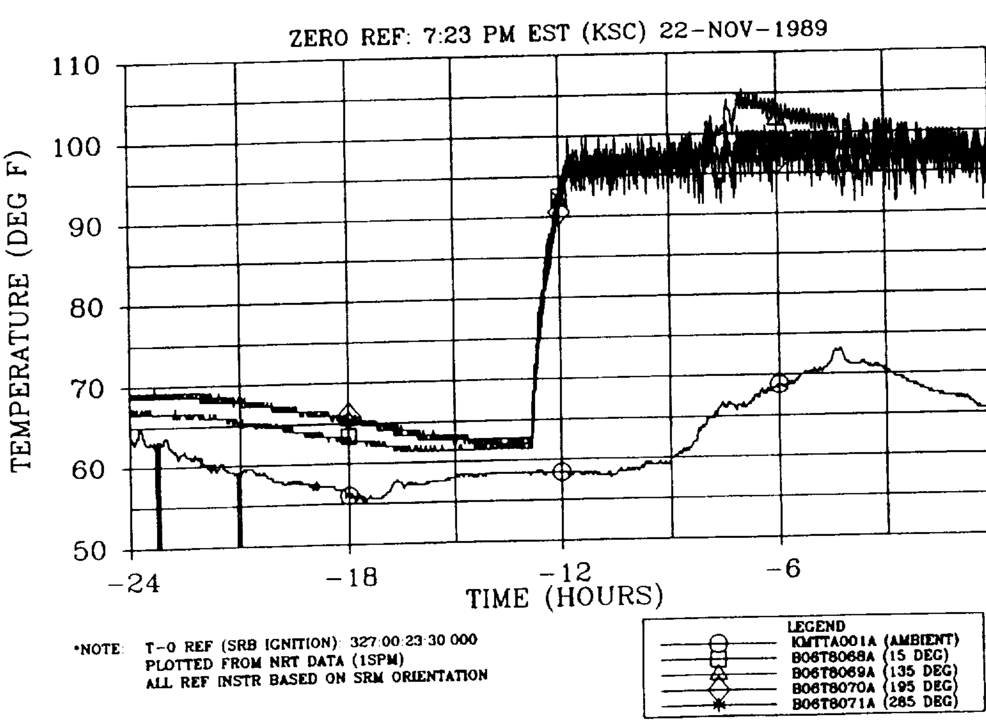

Figure 4.8-48. RH SRM Aft Field Joint Temperature (overlaid with ambient)

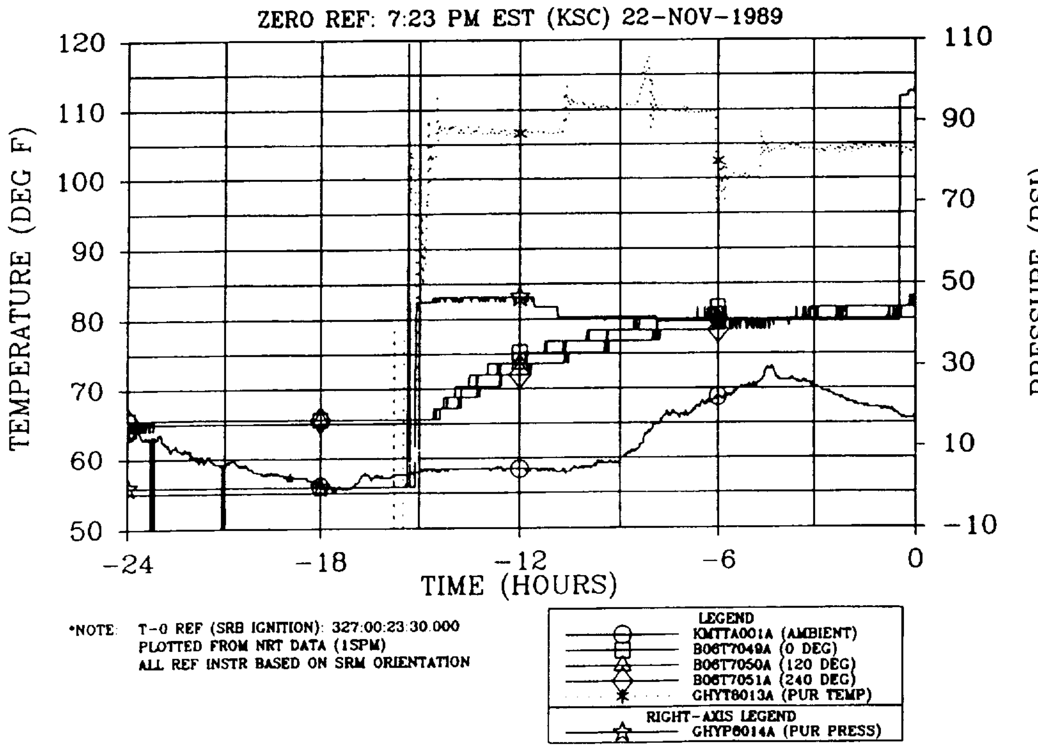

Figure 4.8-49. LH SRM Case-to-Nozzle Joint Temperature (overlaid with ambient)

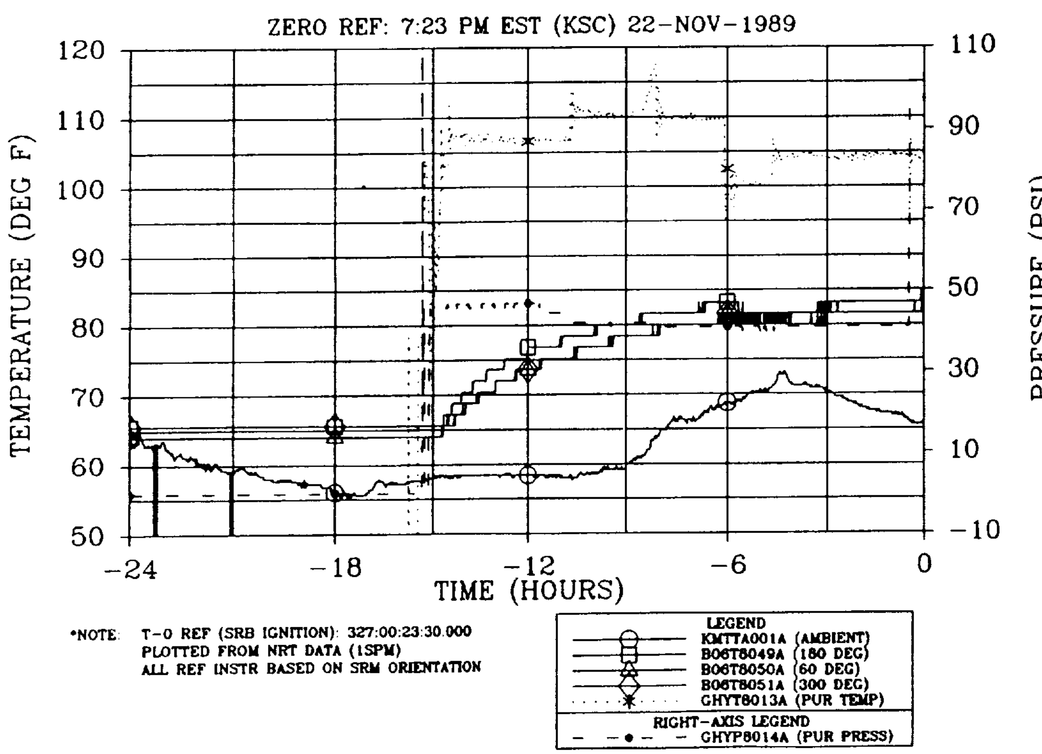

Figure 4.8-50. RH SRM Case-to-Nozzle Joint Temperature (overlaid with ambient)

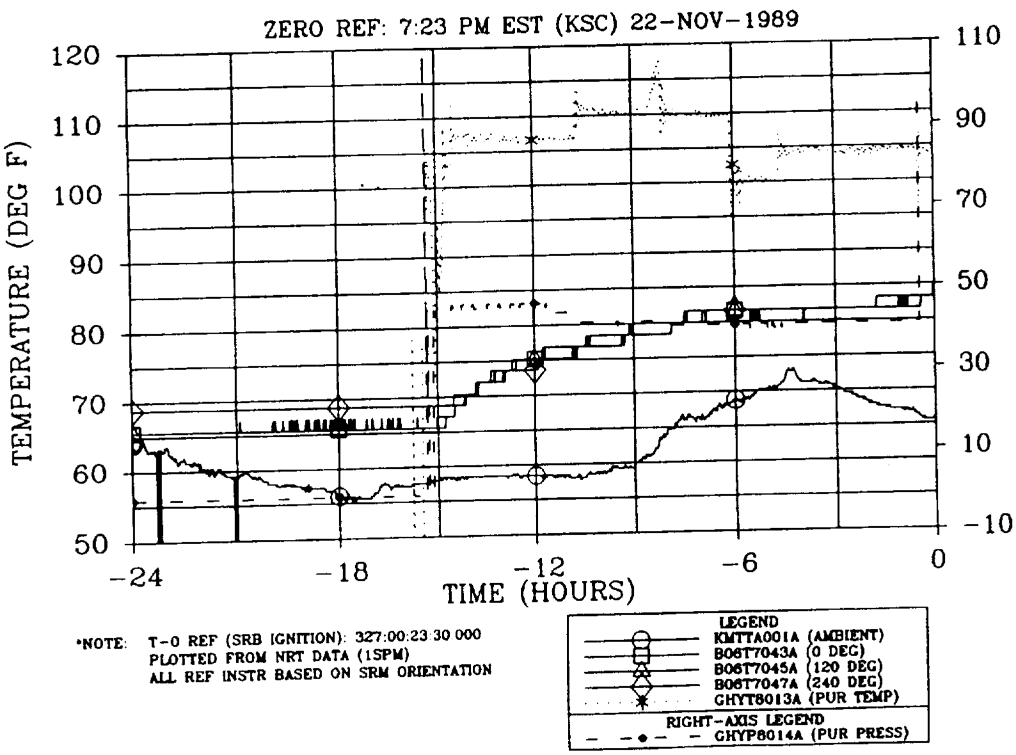

Figure 4.8-51. LH SRM Flex Bearing Aft End Ring Temperature (overlaid with ambient)

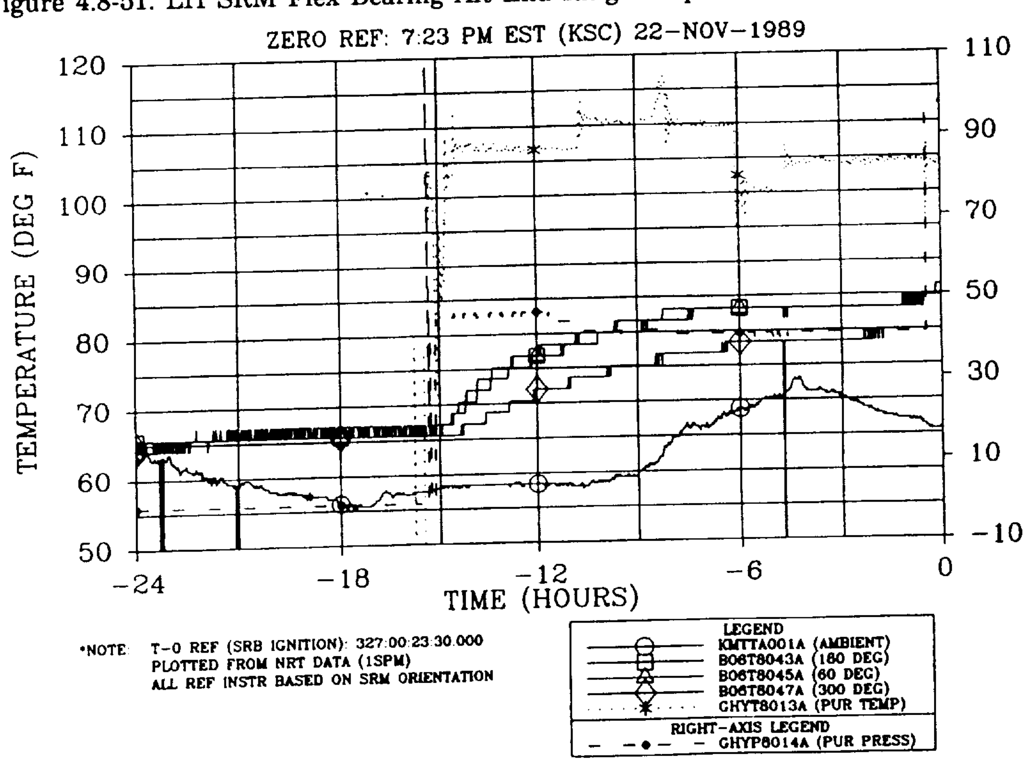

Figure 4.8-52. RH SRM Flex Bearing Aft End Ring Temperature (overlaid with ambient)

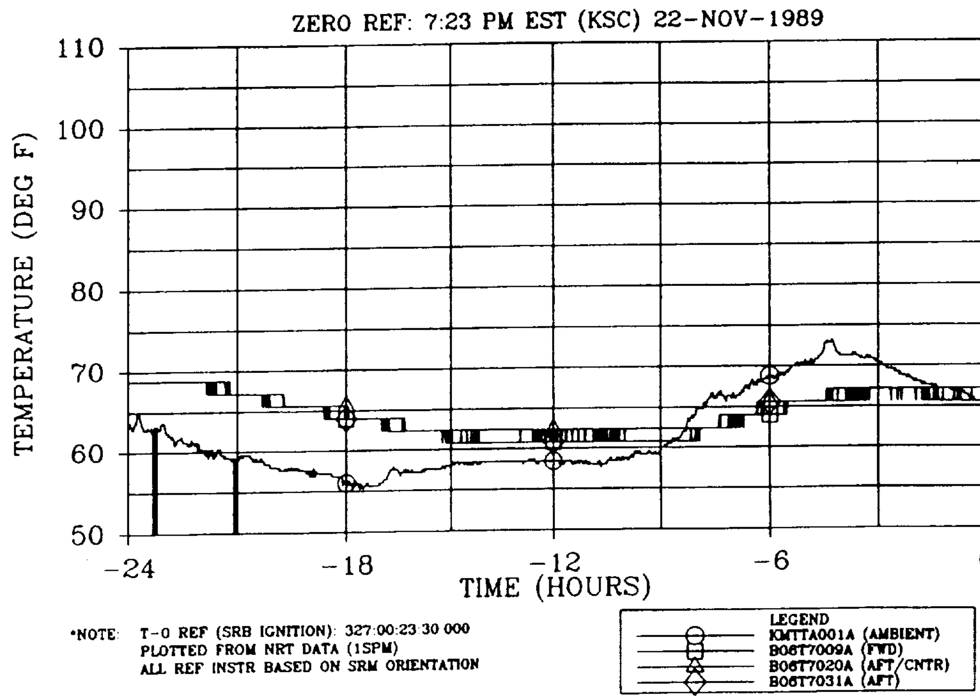

Figure 4.8-53. LH SRM Systems Tunnel Bondline Temperature (overlaid with ambient)

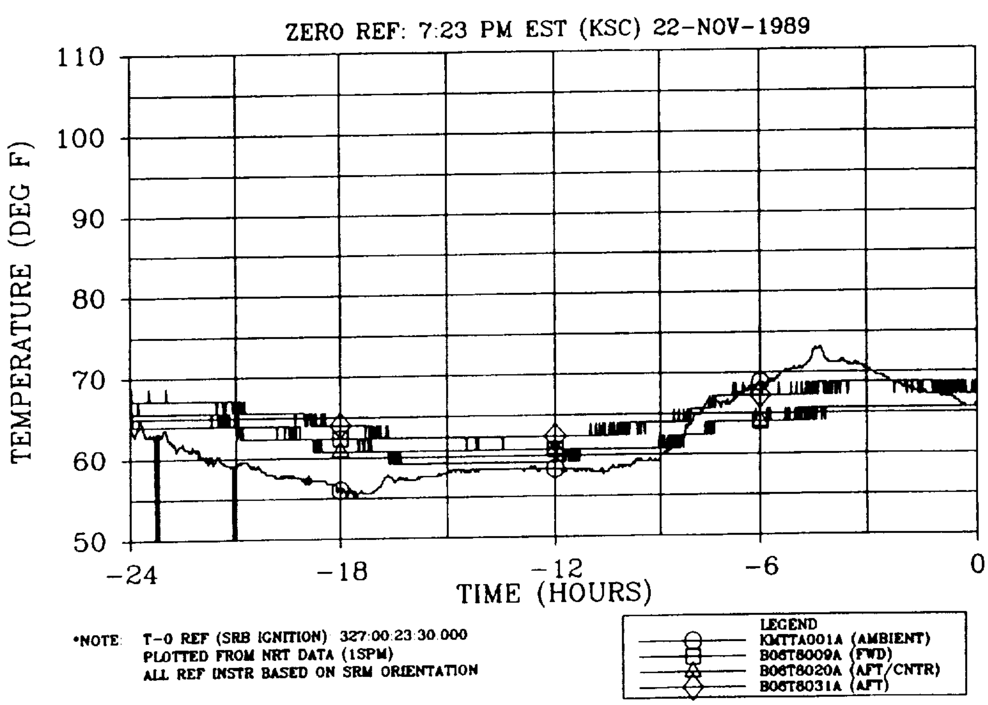

Figure 4.8-54. RH SRM Systems Tunnel Bondline Temperature (overlaid with ambient)

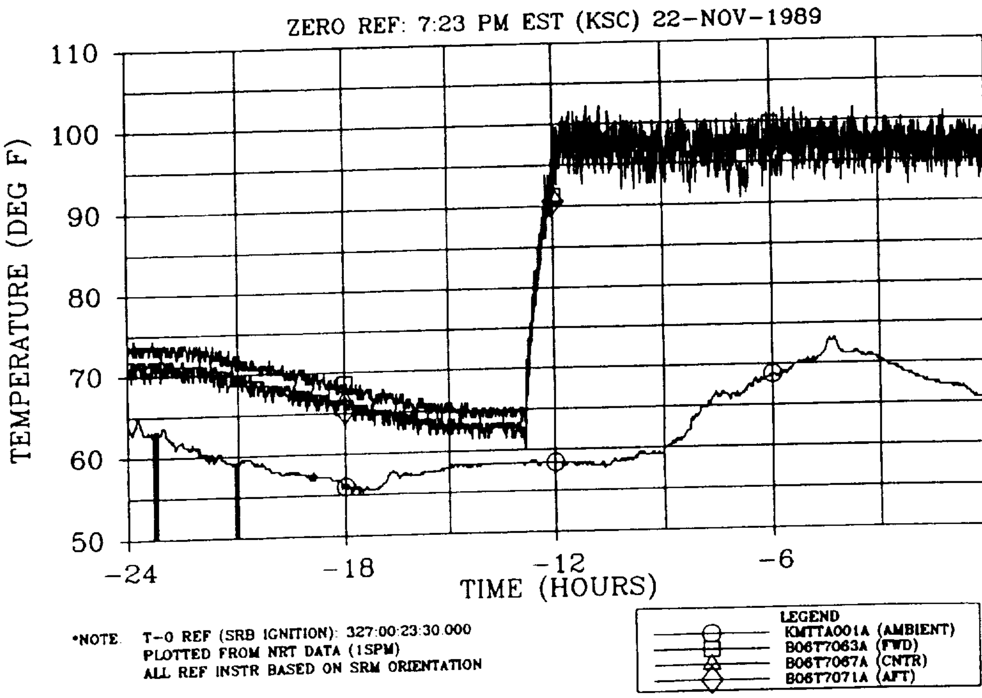

Figure 4.8-55. LH SRM Field Joint Temperature at 285 Deg (overlaid with ambient)

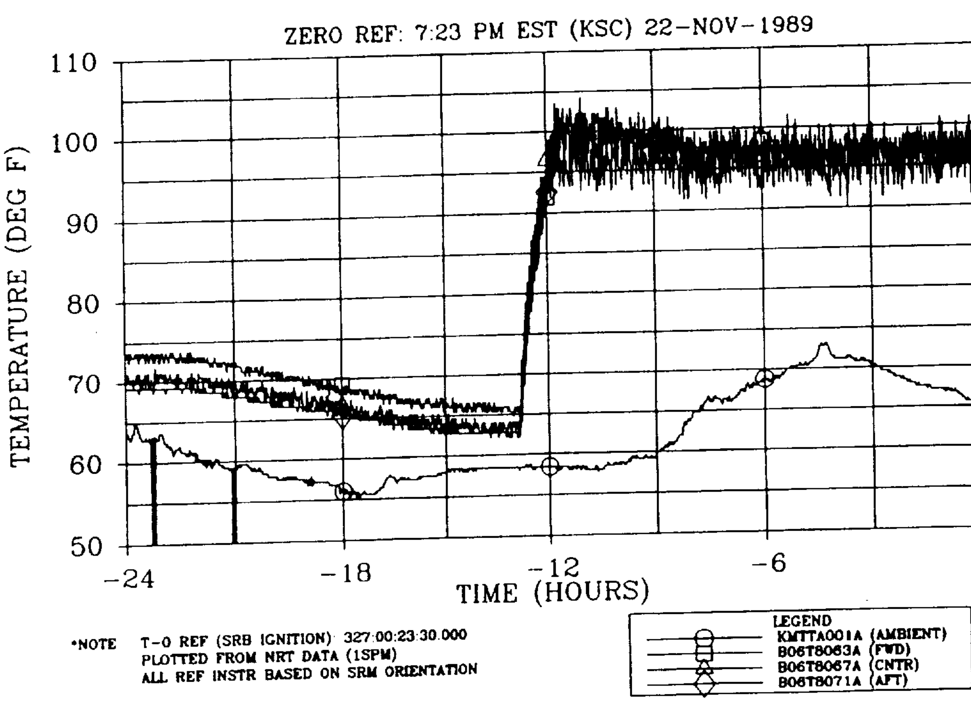

Figure 4.8-56. RH SRM Field Joint Temperature at 285 Deg (overlaid with ambient)

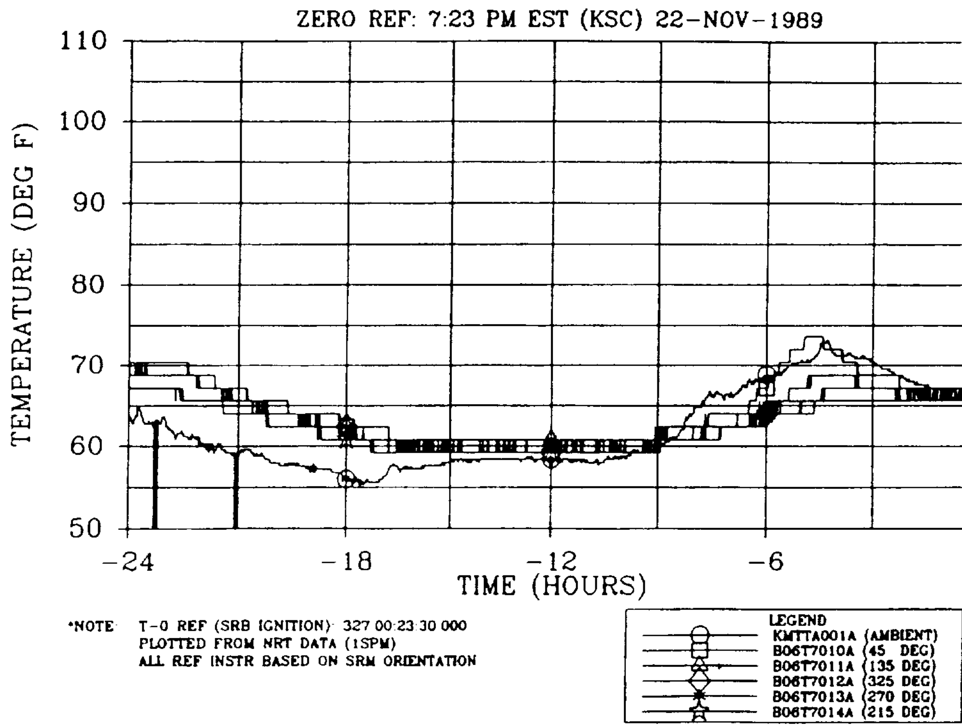

Figure 4.8-57. LH SRM Case Acreage Temperature at Station 931.5 (overlaid with ambient)

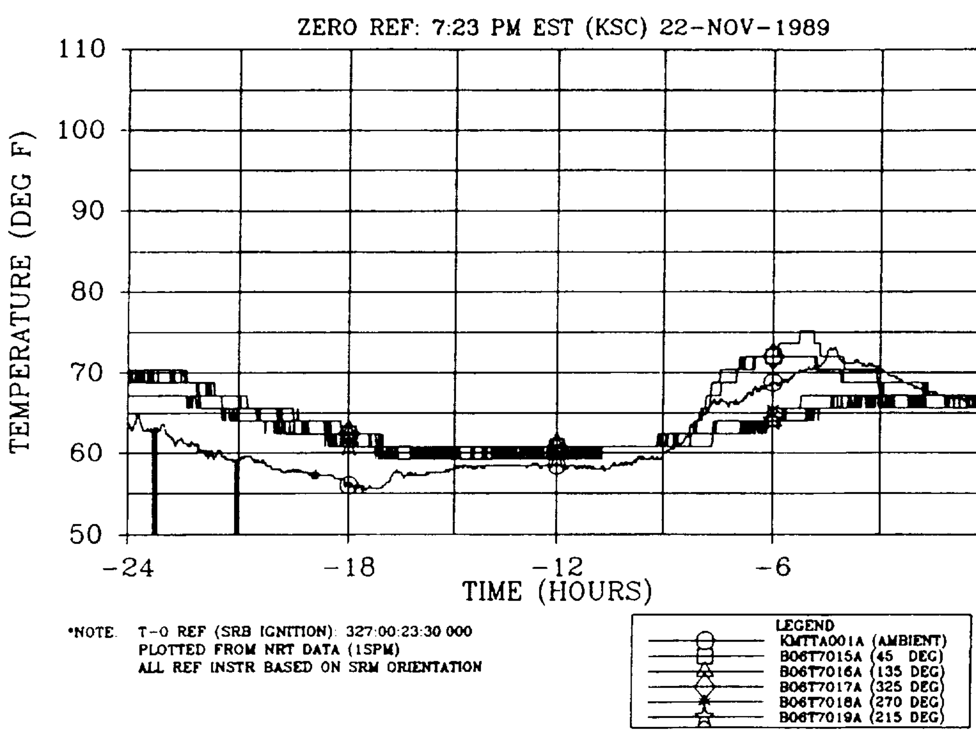

Figure 4.8-58. LH SRM Case Acreage Temperature at Station 1091.5 (overlaid with ambient)

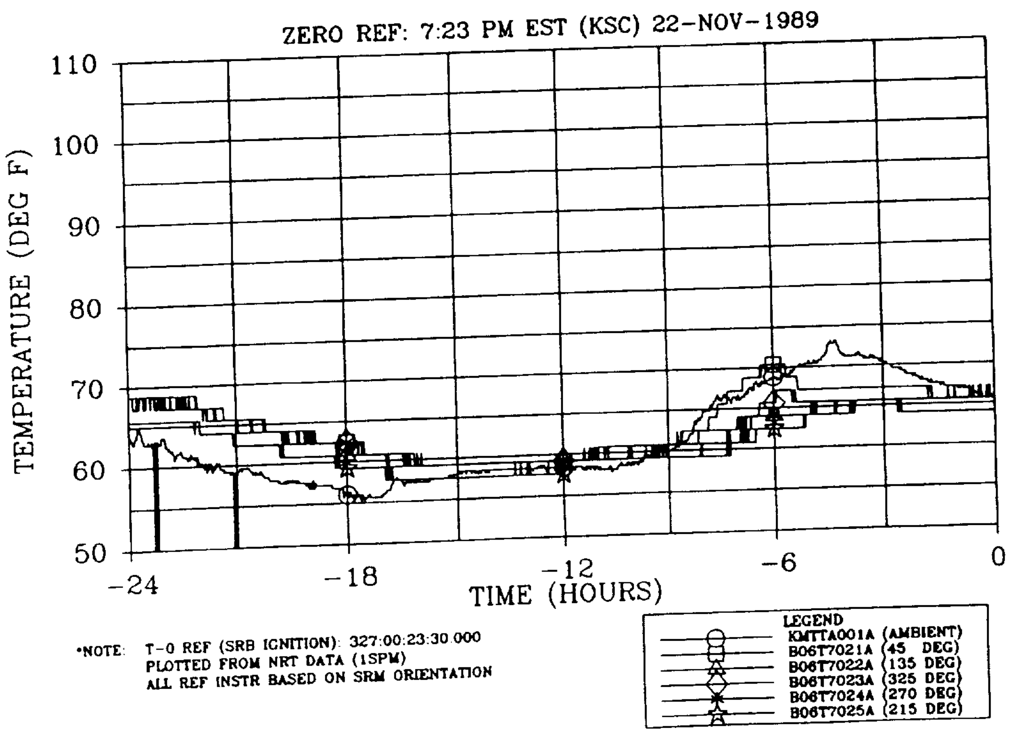

Figure 4.8-59. LH SRM Case Acreage Temperature at Station 1411.5 (overlaid with ambient)

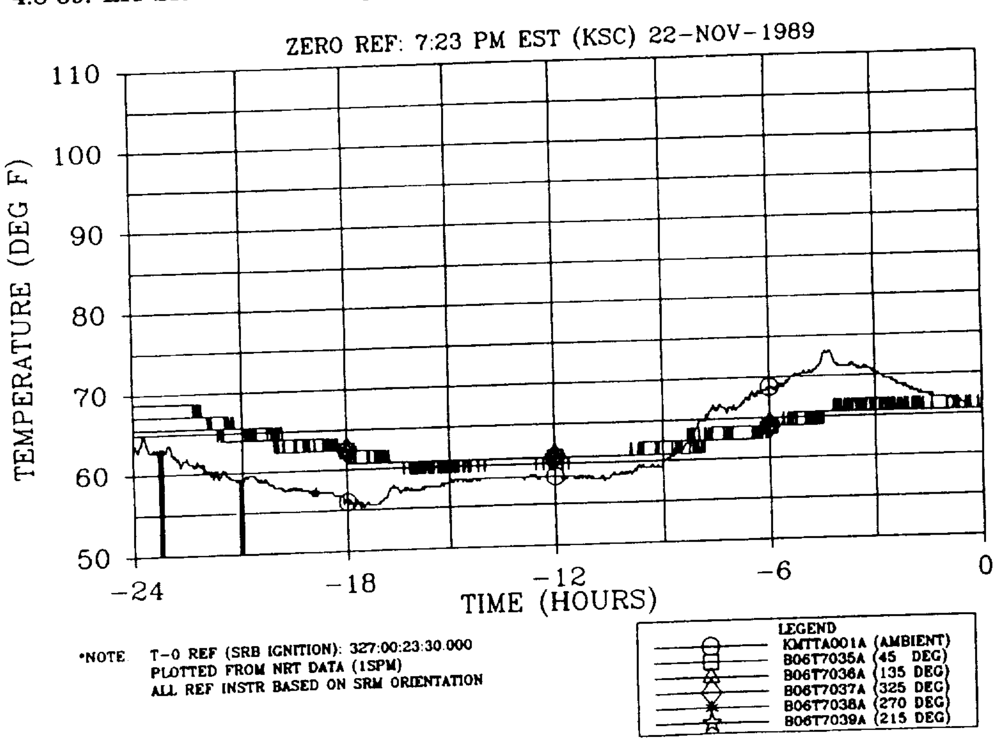

Figure 4.8-60. LH SRM Case Acreage Temperature at Station 1751.5 (overlaid with ambient)

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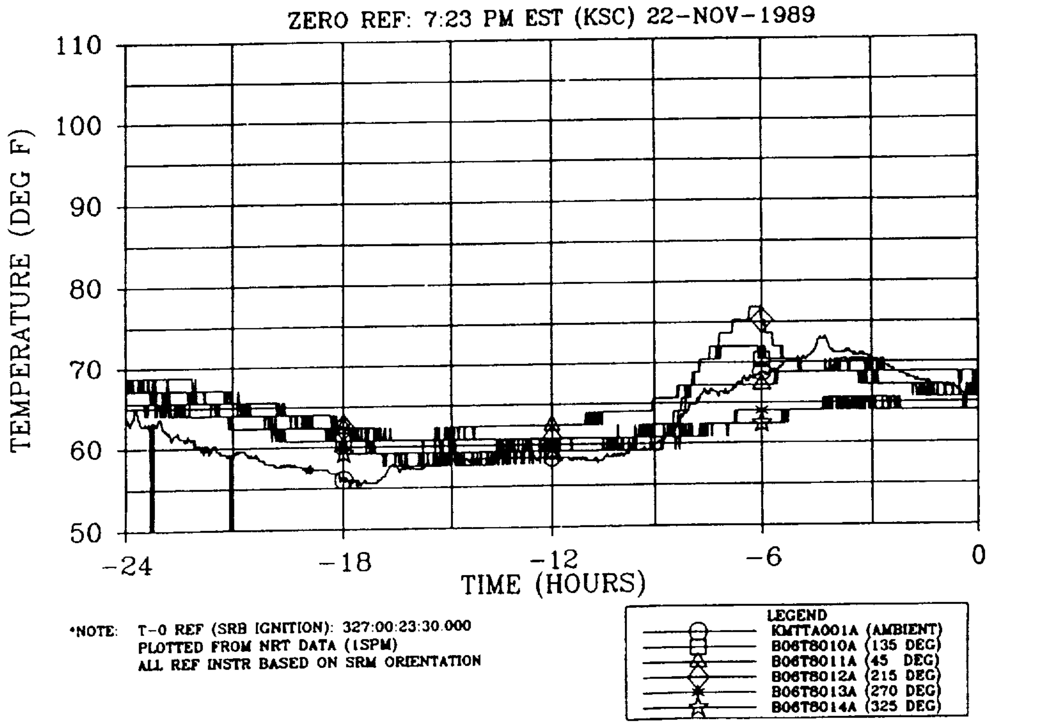


Figure 4.8-61. RH SRM Case Acreage Temperature at Station 931.5 (overlaid with ambient)

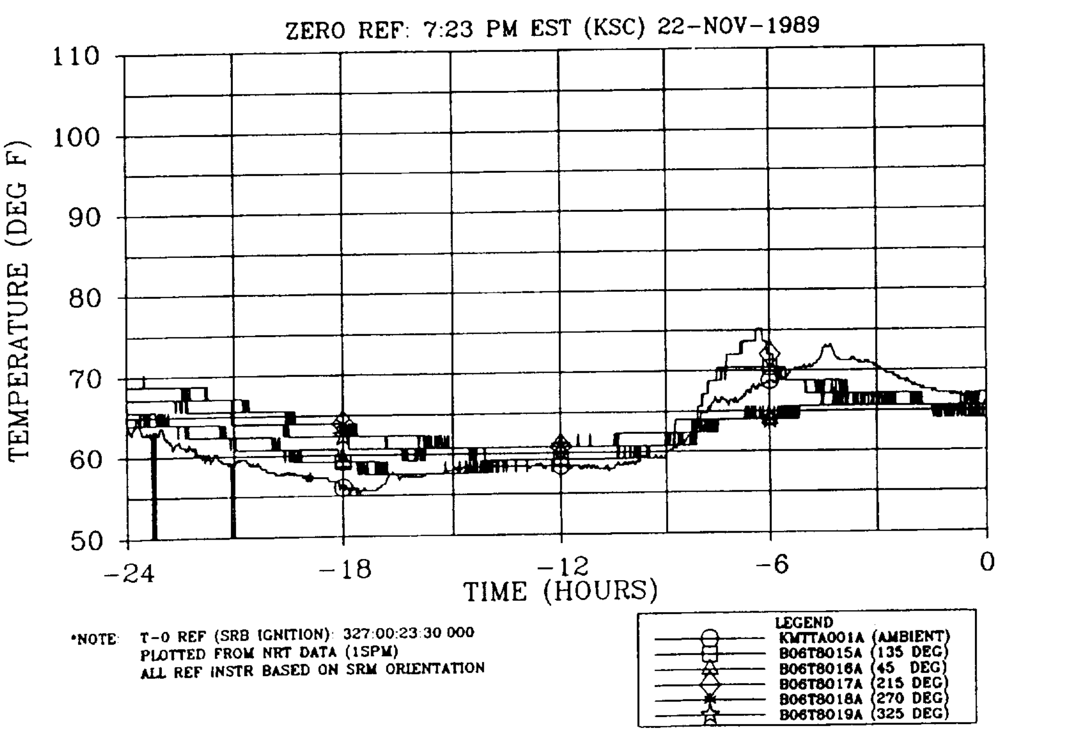


Figure 4.8-62. RH SRM Case Acreage Temperature at Station 1091.5 (overlaid with ambient)

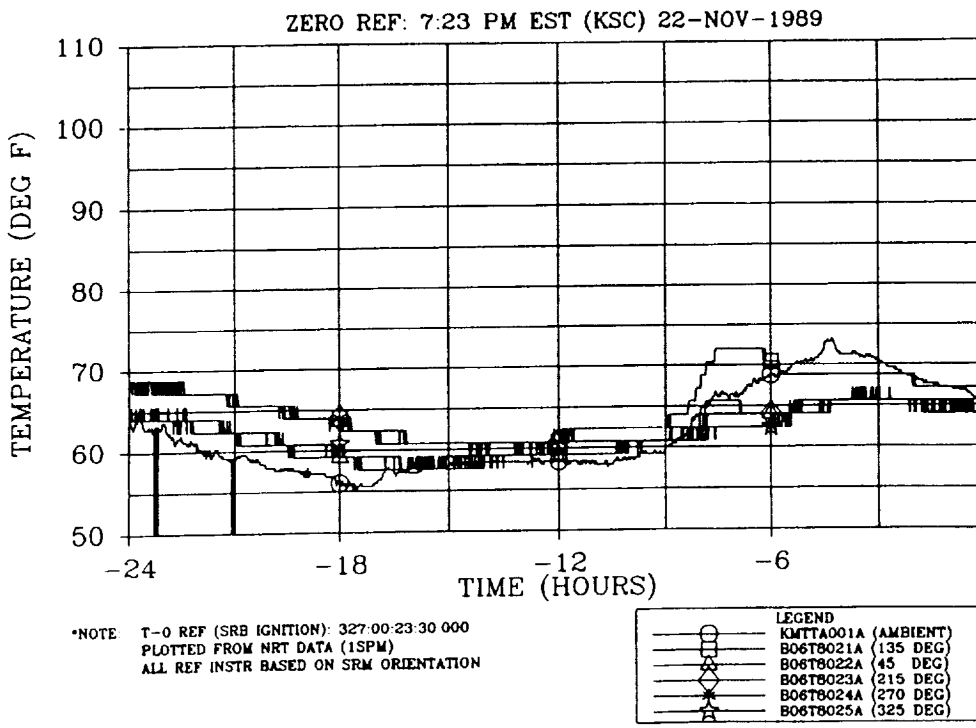


Figure 4.8-63. RH SRM Case Acreage Temperature at Station 1411.5 (overlaid with ambient)

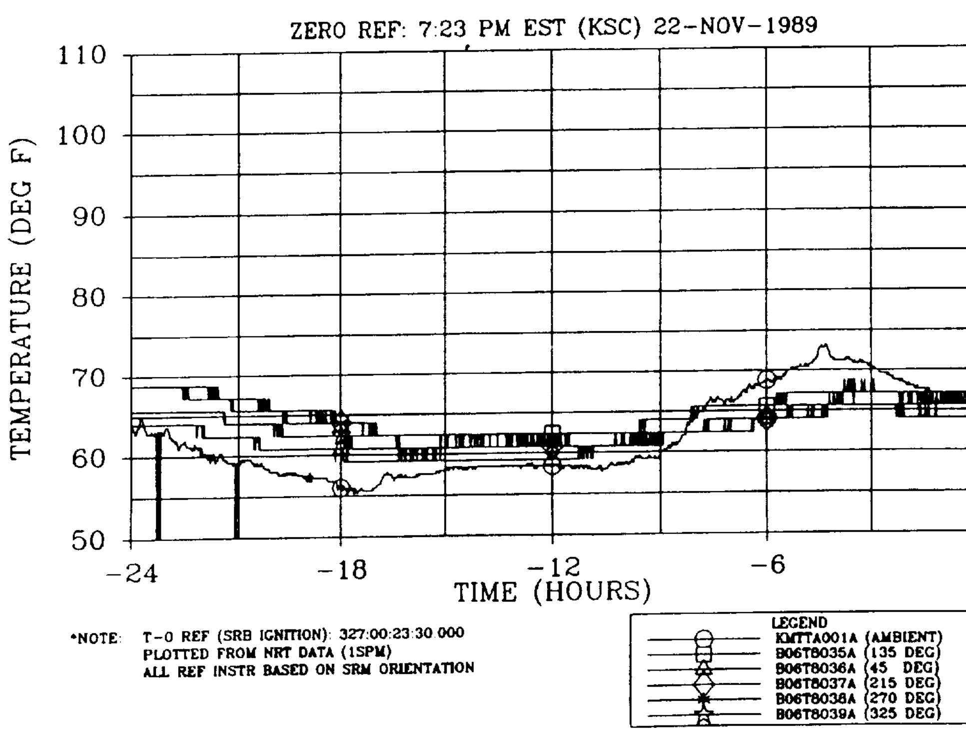


Figure 4.8-64. RH SRM Case Acreage Temperature at Station 1751.5 (overlaid with ambient)

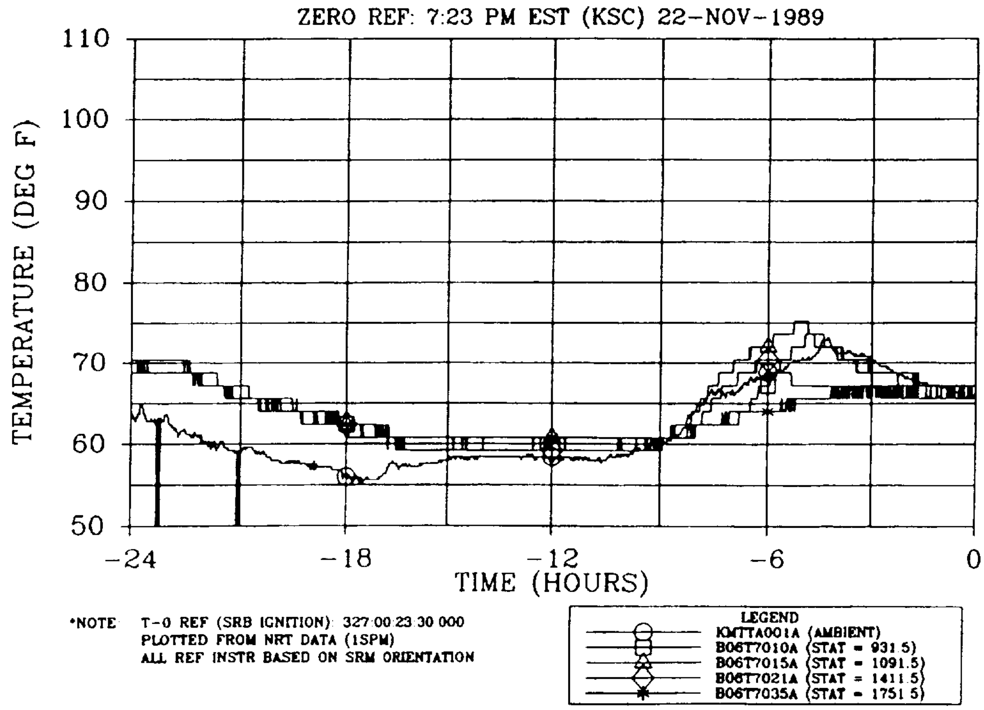


Figure 4.8-65. LH SRM Case Acreage Temperature at 45 Deg (overlaid with ambient)

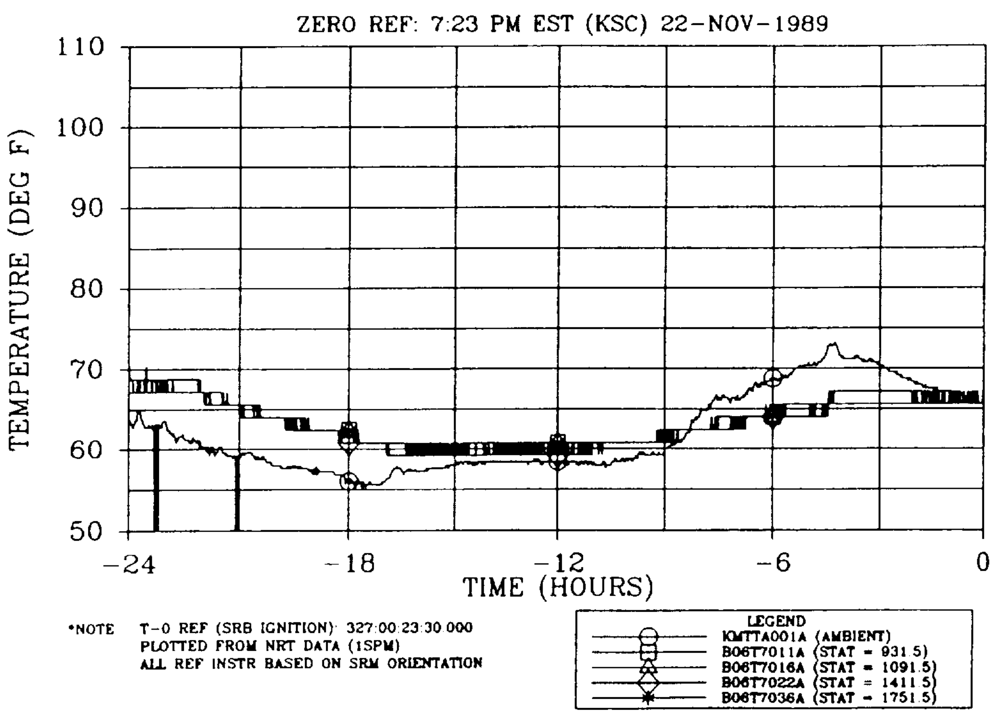


Figure 4.8-66. LH SRM Case Acreage Temperature at 135 Deg (overlaid with ambient)

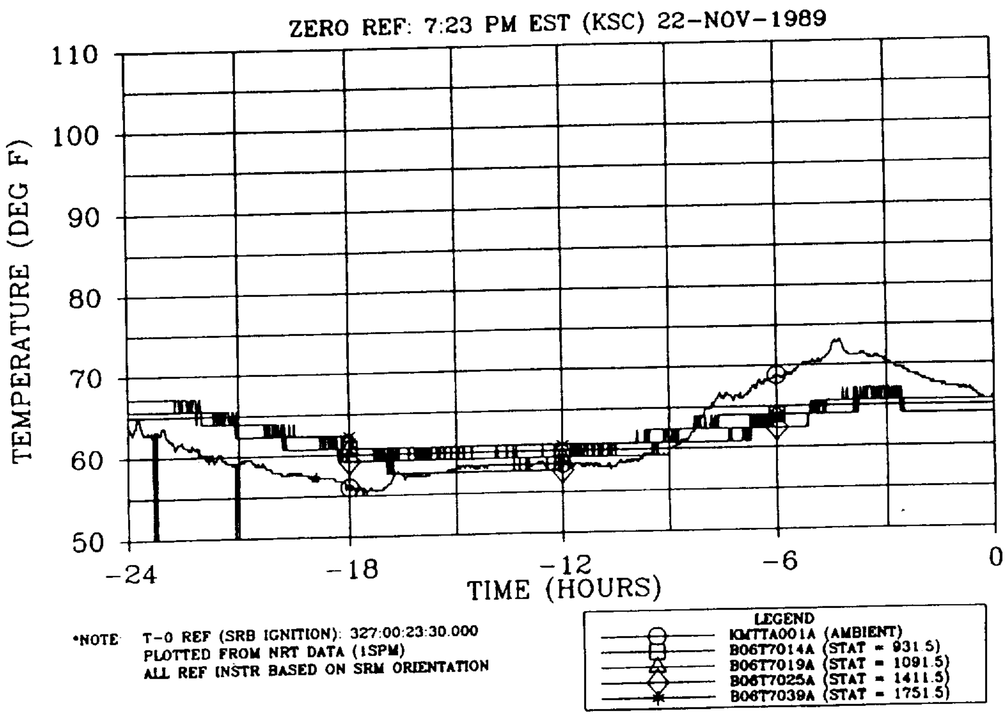


Figure 4.8-67. LH SRM Case Acreage Temperature at 215 Deg (overlaid with ambient)

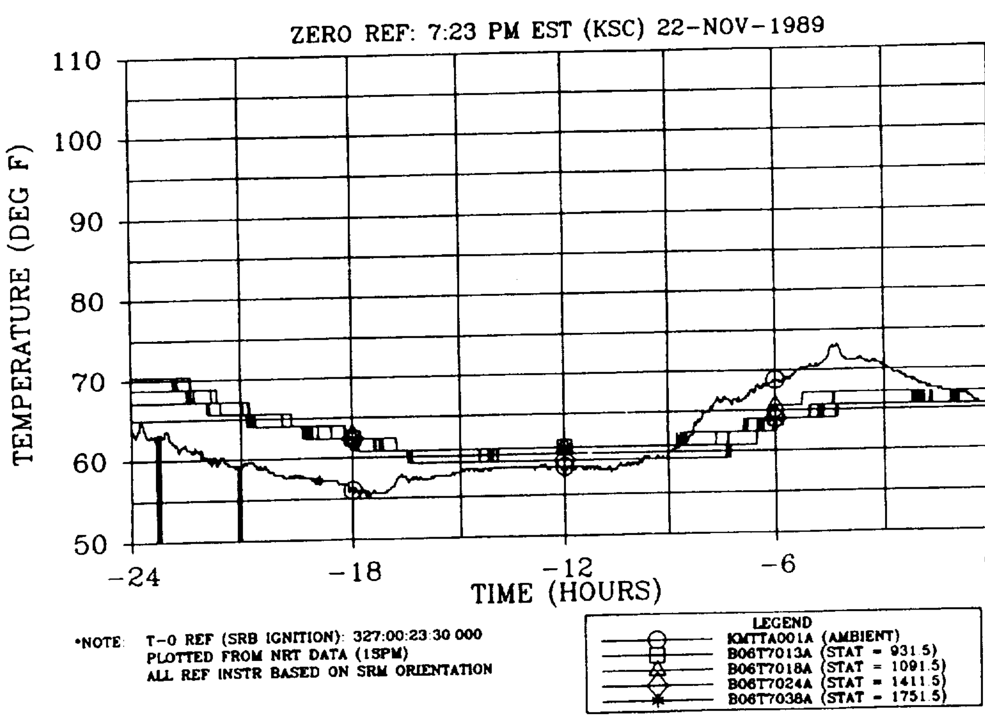


Figure 4.8-68. LH SRM Case Acreage Temperature at 270 Deg (overlaid with ambient)

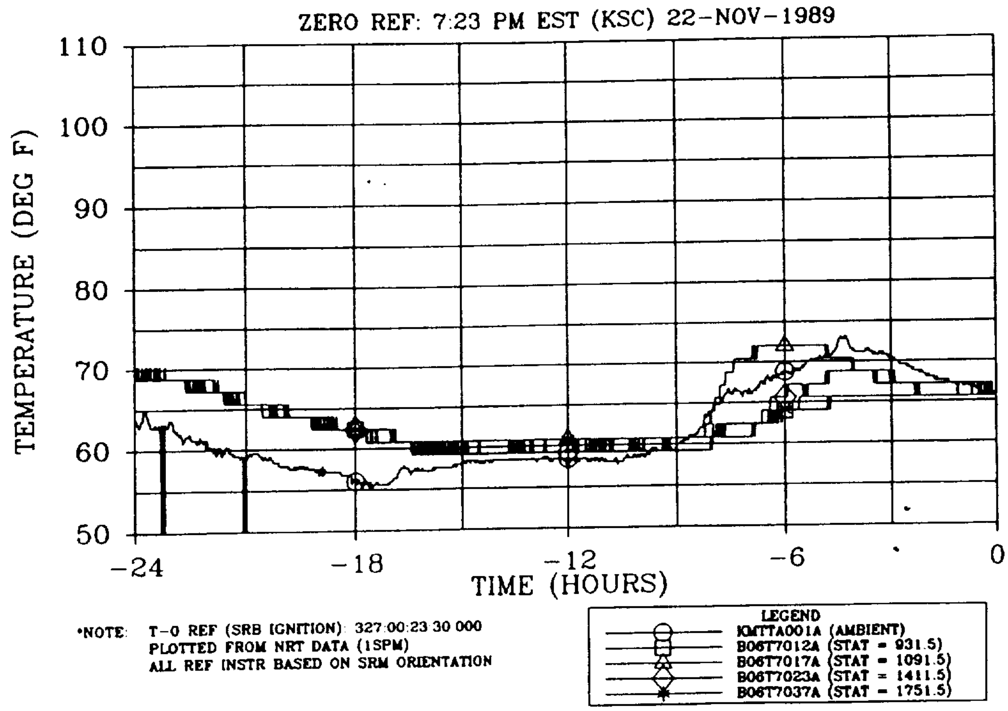


Figure 4.8-69. LH SRM Case Acreage Temperature at 325 Deg (overlaid with ambient)

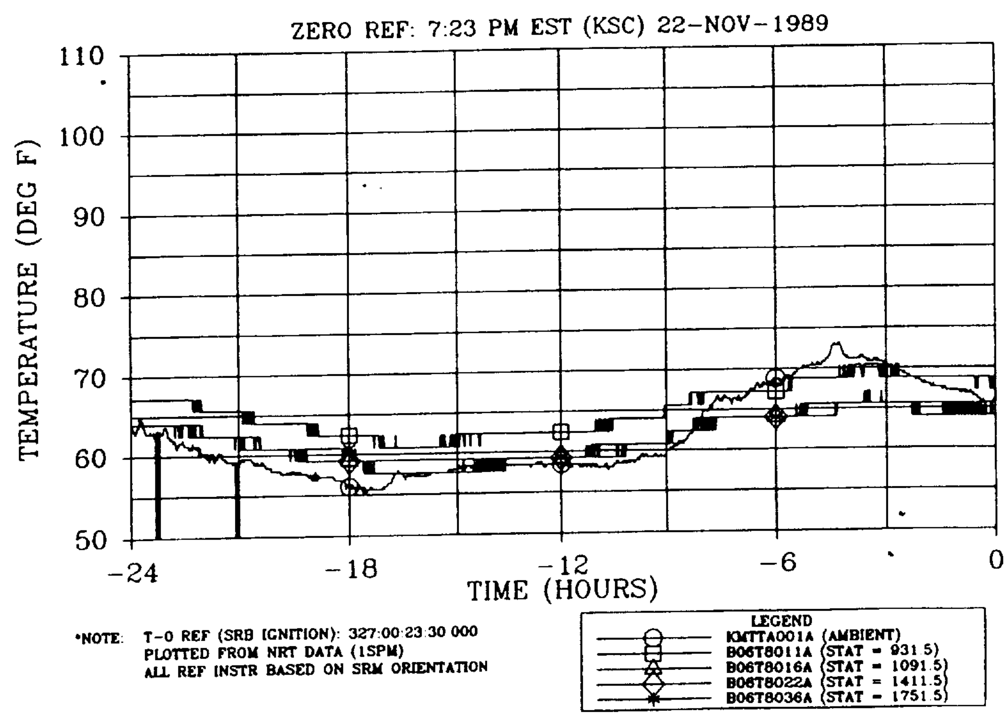


Figure 4.8-70. RH SRM Case Acreage Temperature at 45 Deg (overlaid with ambient)

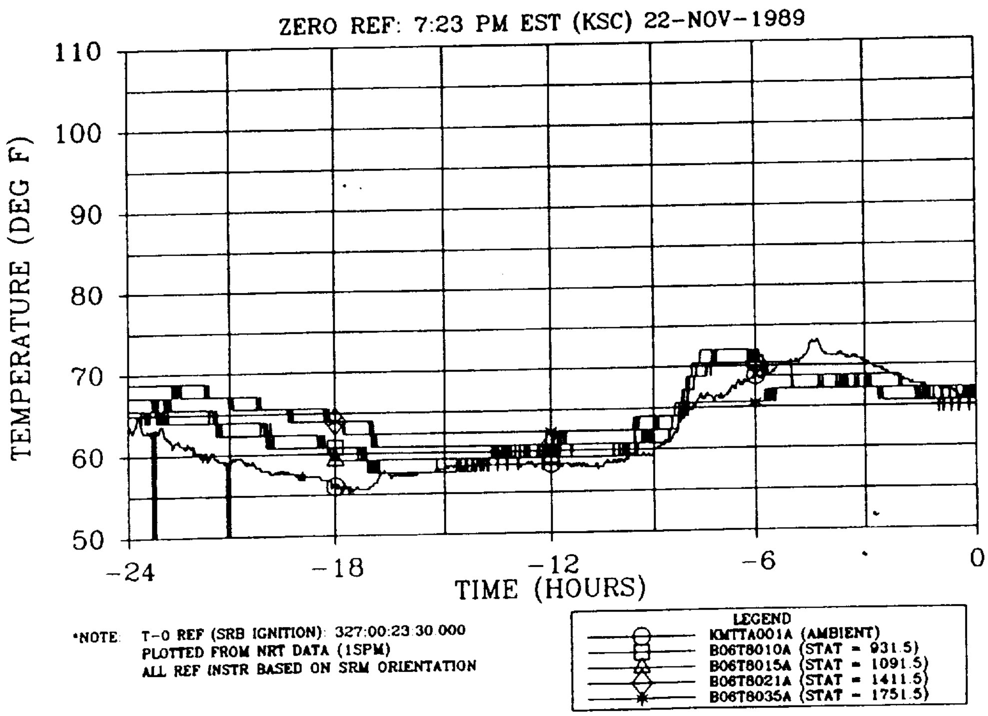


Figure 4.8-71. RH SRM Case Acreage Temperature at 135 Deg (overlaid with ambient)

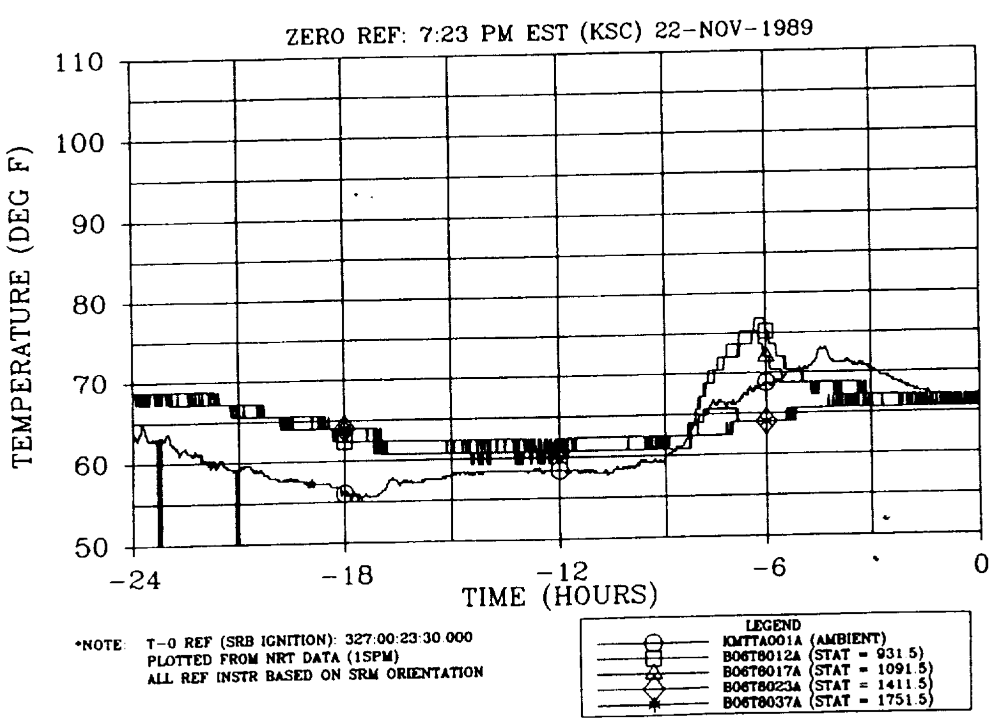


Figure 4.8-72. RH SRM Case Acreage Temperature at 215 Deg (overlaid with ambient)

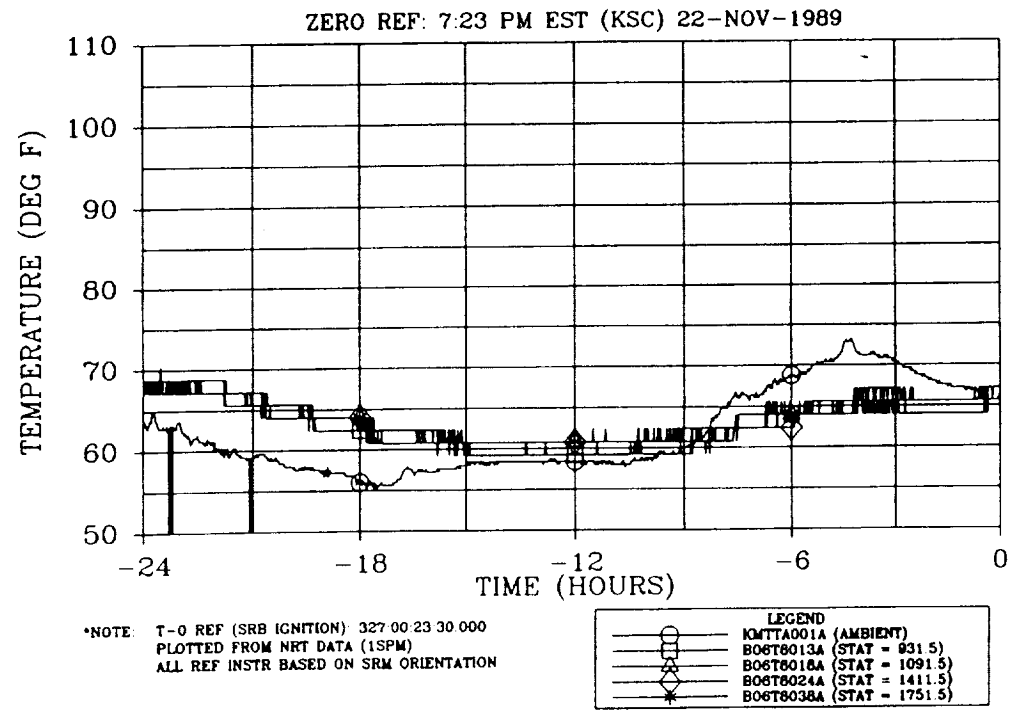


Figure 4.8-73. RH SRM Case Acreage Temperature at 270 Deg (overlaid with ambient)

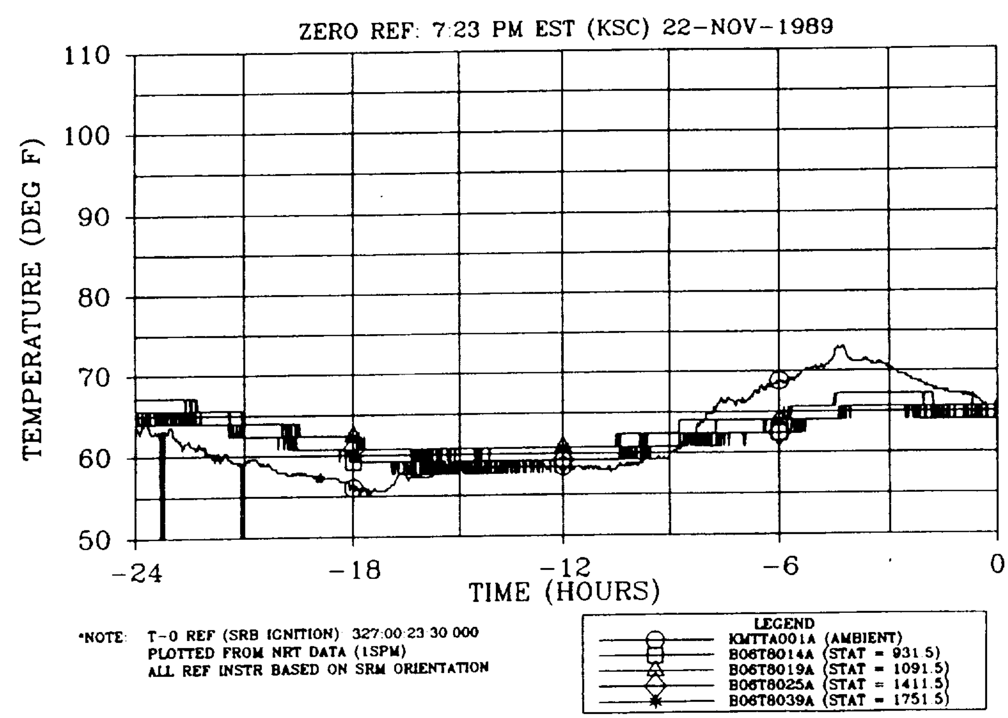


Figure 4.8-74. RH SRM Case Acreage Temperature at 325 Deg (overlaid with ambient)

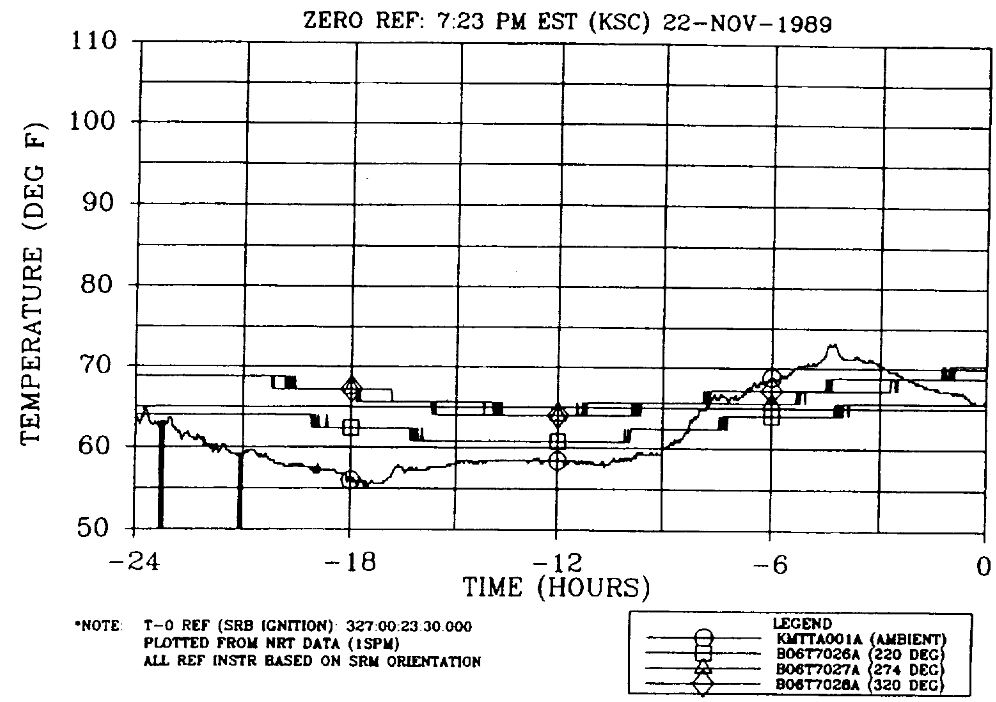


Figure 4.8-75. LH SRM ET Attach Region Temperature at Station 1511.0 (overlaid with ambient)

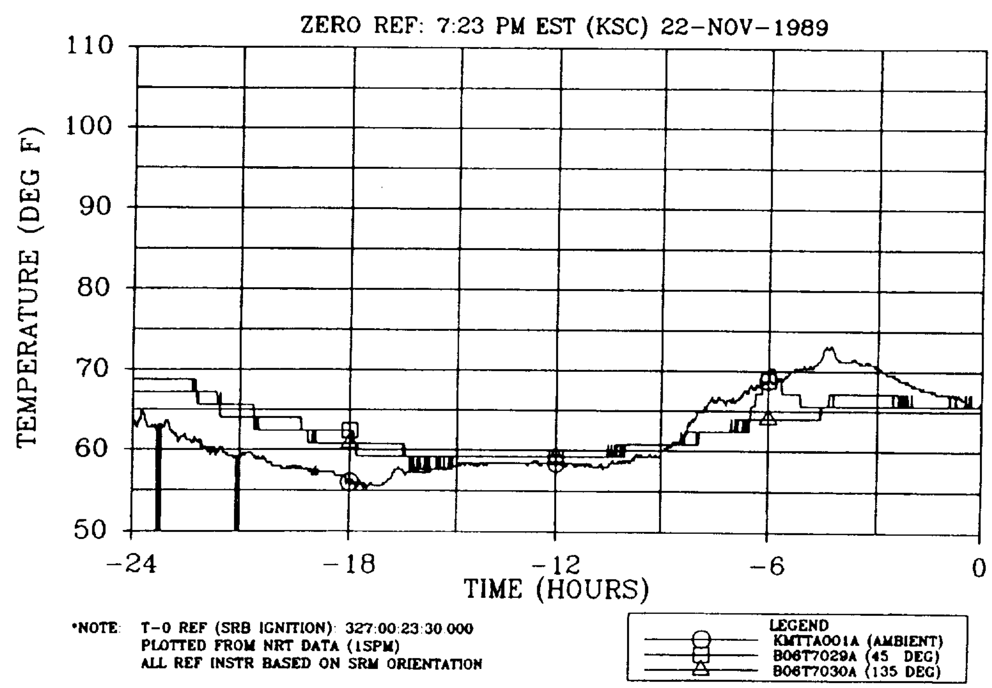


Figure 4.8-76. LH SRM ET Attach Region Temperature at Station 1535.0 (overlaid with ambient)

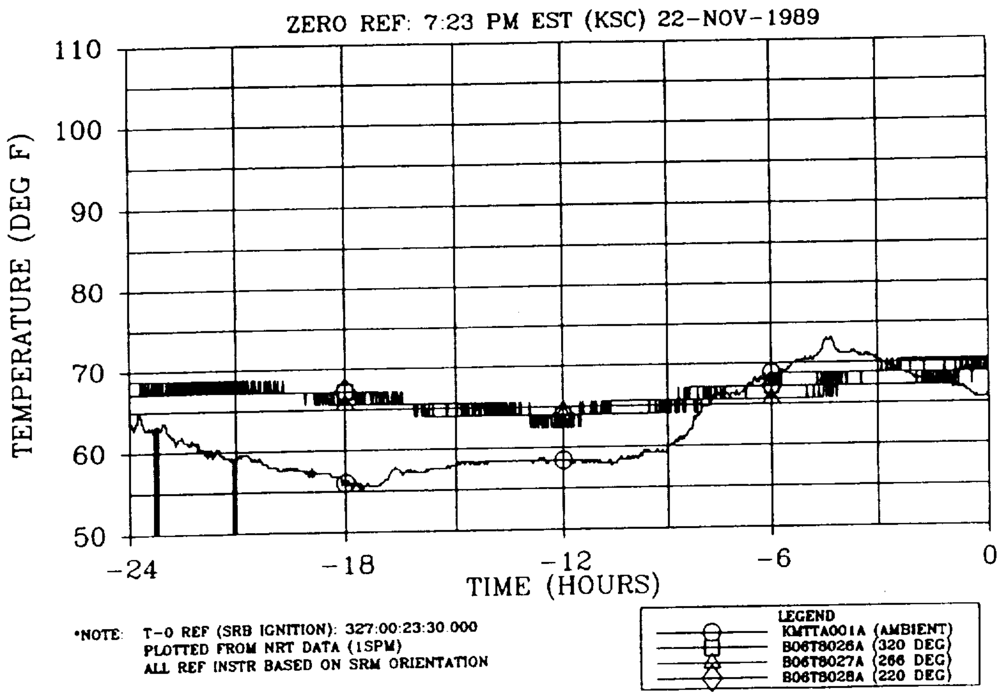


Figure 4.8-77. RH SRM ET Attach Region Temperature at Station 1511.0 (overlaid with ambient)

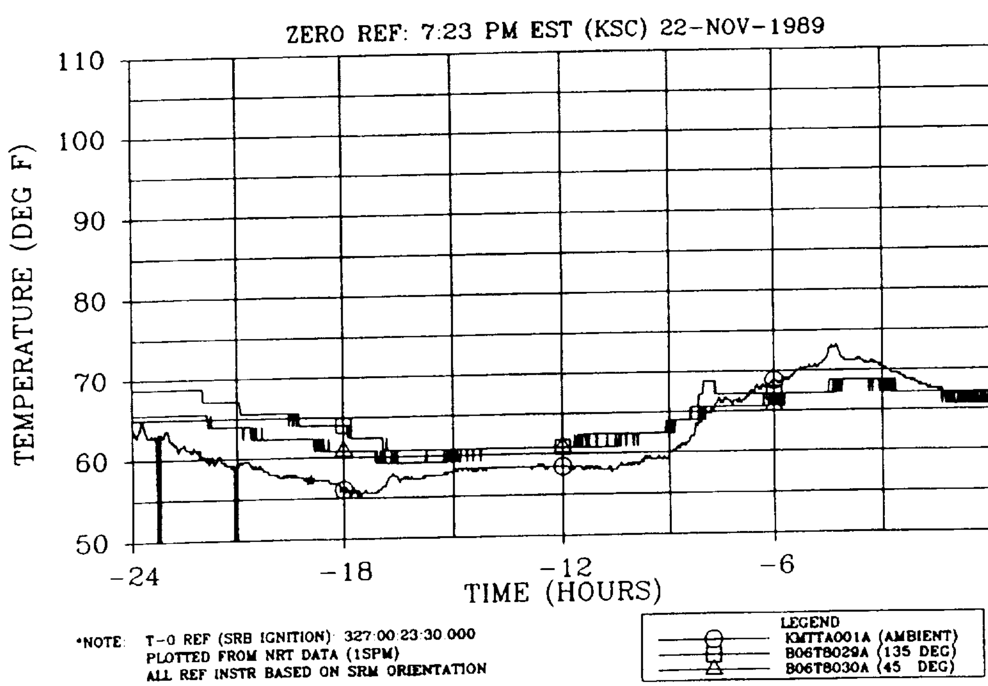


Figure 4.8-78. RH SRM ET Attach Region Temperature at Station 1535.0 (overlaid with ambient)

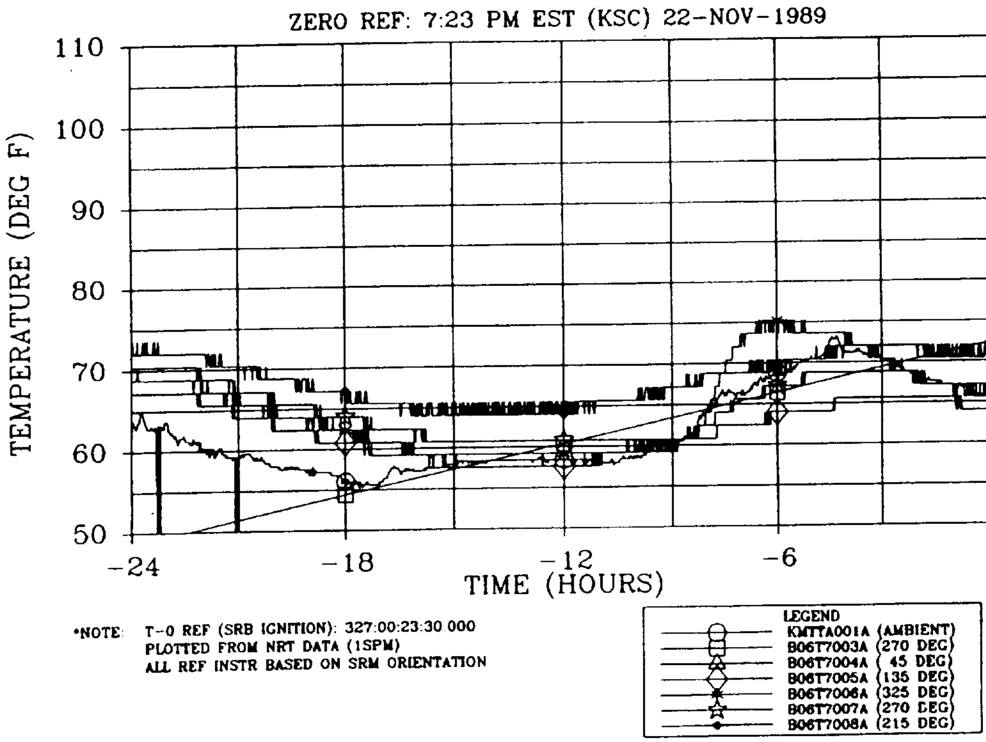


Figure 4.8-79. LH SRM Forward Factory Joint Temperature (overlaid with ambient)

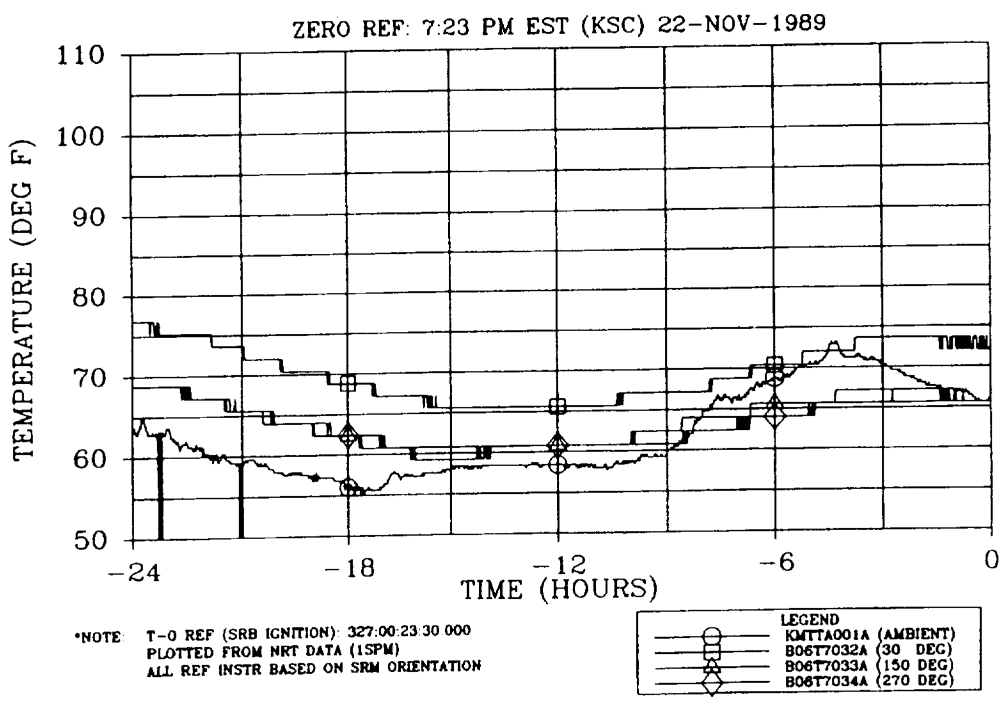


Figure 4.8-80. LH SRM Aft Factory Joint Temperature at Station 1701.9 (overlaid with ambient)

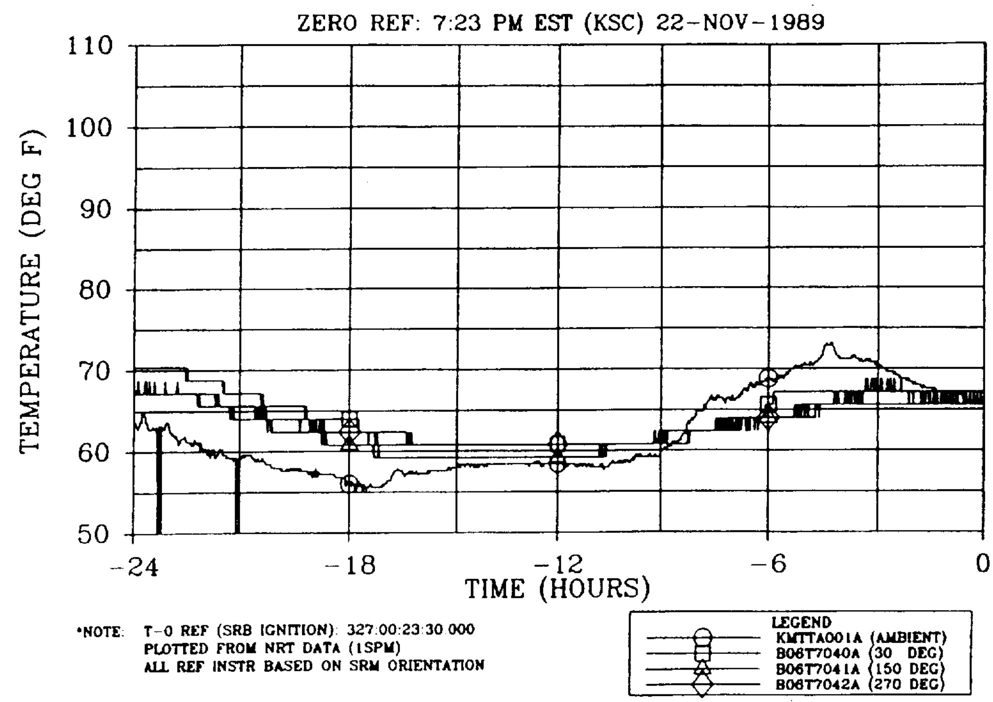


Figure 4.8-81. LH SRM Aft Factory Joint Temperature at Station 1821.0 (overlaid with ambient)

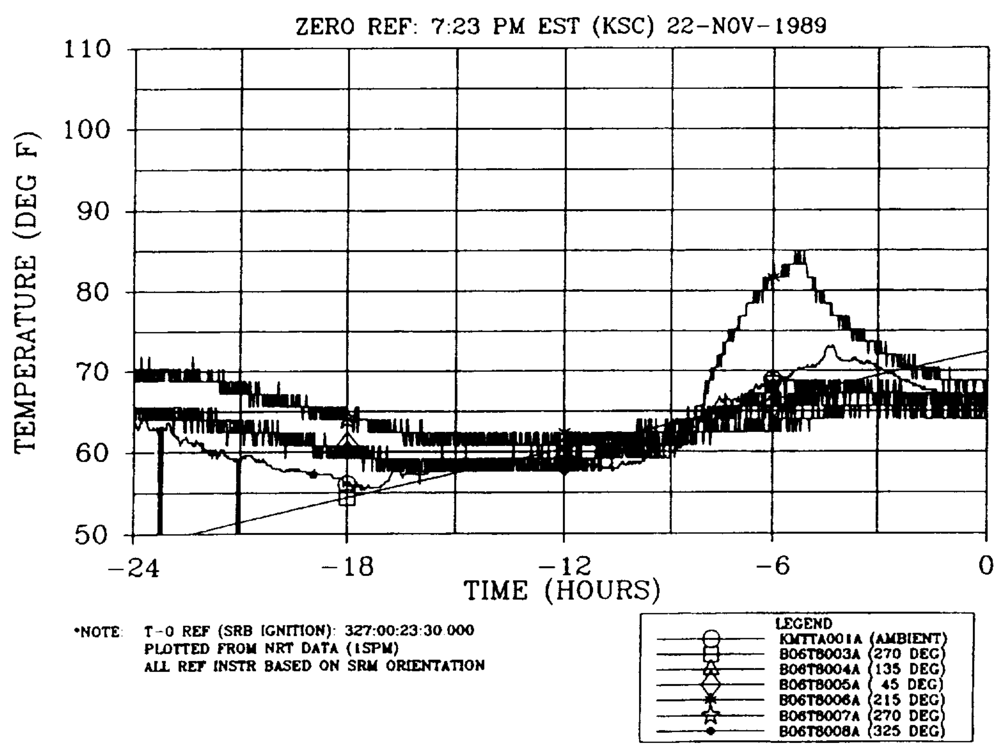
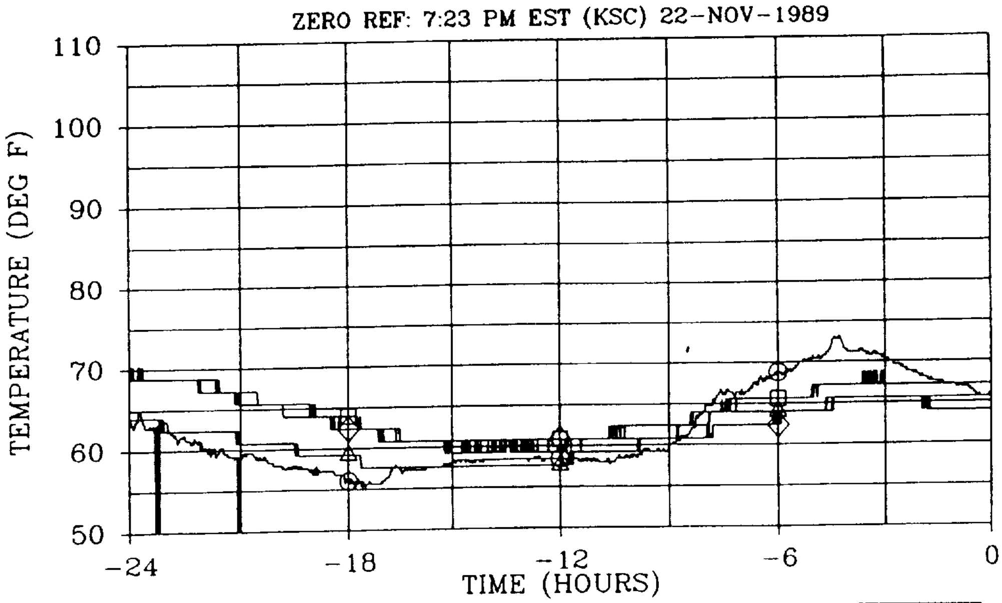


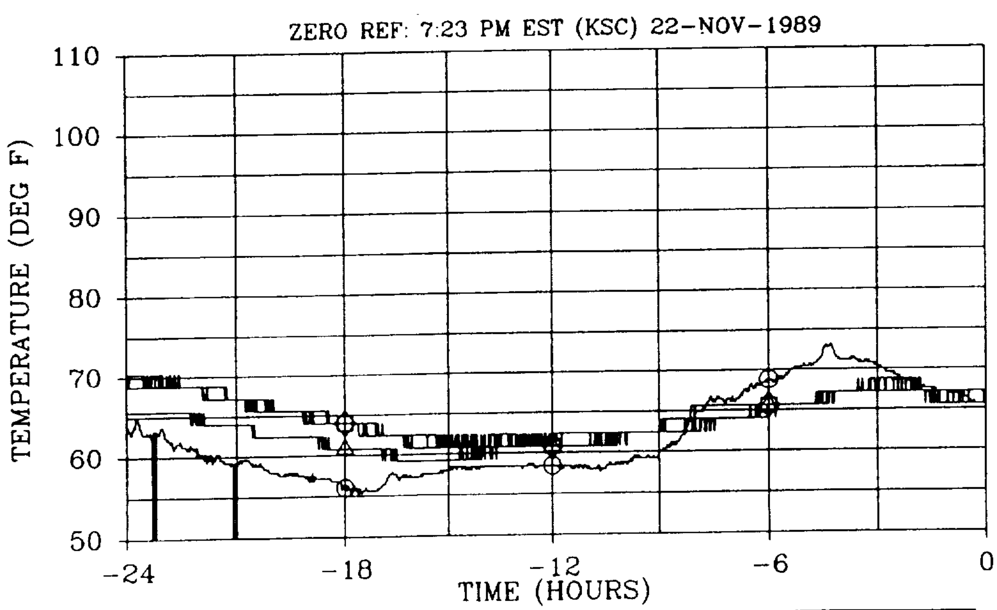
Figure 4.8-82. RH SRM Forward Factory Joint Temperature (overlaid with ambient)



*NOTE: T-0 REF (SRB IGNITION): 327:00:23:30.000
PLOTTED FROM NRT DATA (1SPM)
ALL REF INSTR BASED ON SRM ORIENTATION

LEGEND
KMTTA001A (AMBIENT)
B06T8032A (150 DEG)
B06T8033A (30 DEG)
B06T8034A (270 DEG)

Figure 4.8-83. RH SRM Aft Factory Joint Temperature at Station 1701.9 (overlaid with ambient)



*NOTE: T-0 REF (SRB IGNITION): 327:00:23:30.000
PLOTTED FROM NRT DATA (1SPM)
ALL REF INSTR BASED ON SRM ORIENTATION

LEGEND
KMTTA001A (AMBIENT)
B06T8040A (150 DEG)
B06T8041A (30 DEG)
B06T8042A (270 DEG)

Figure 4.8-84. RH SRM Aft Factory Joint Temperature at Station 1821.0 (overlaid with ambient)

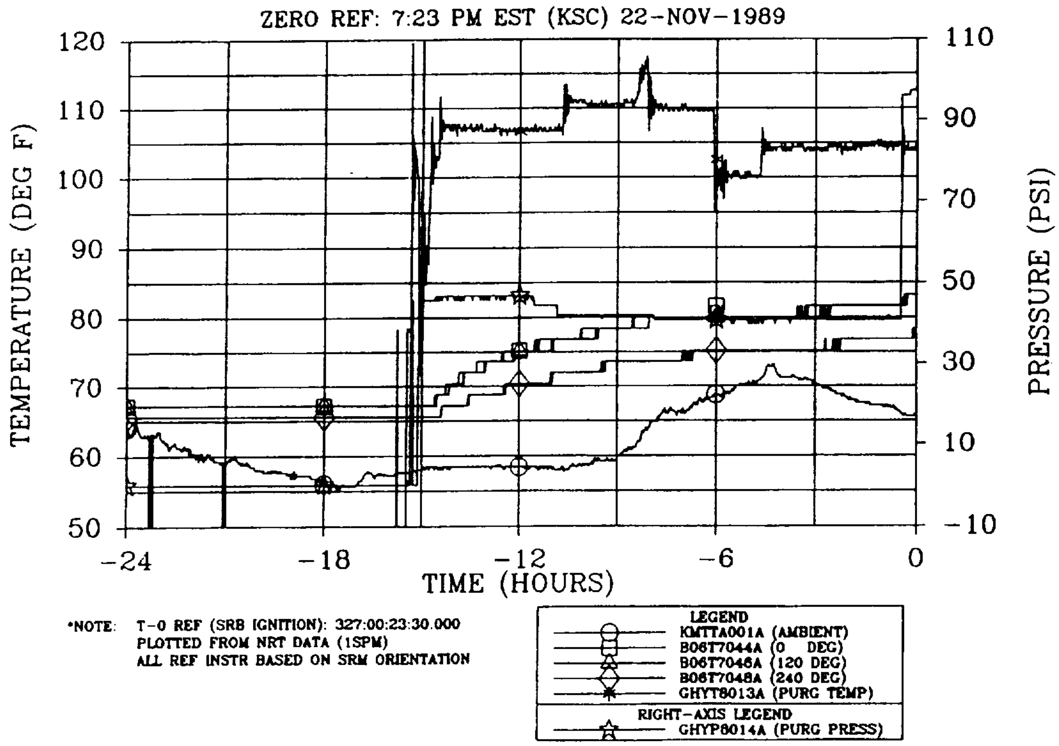


Figure 4.8-85. LH SRM Nozzle Region Temperature at Station 1845.0 (overlaid with ambient)

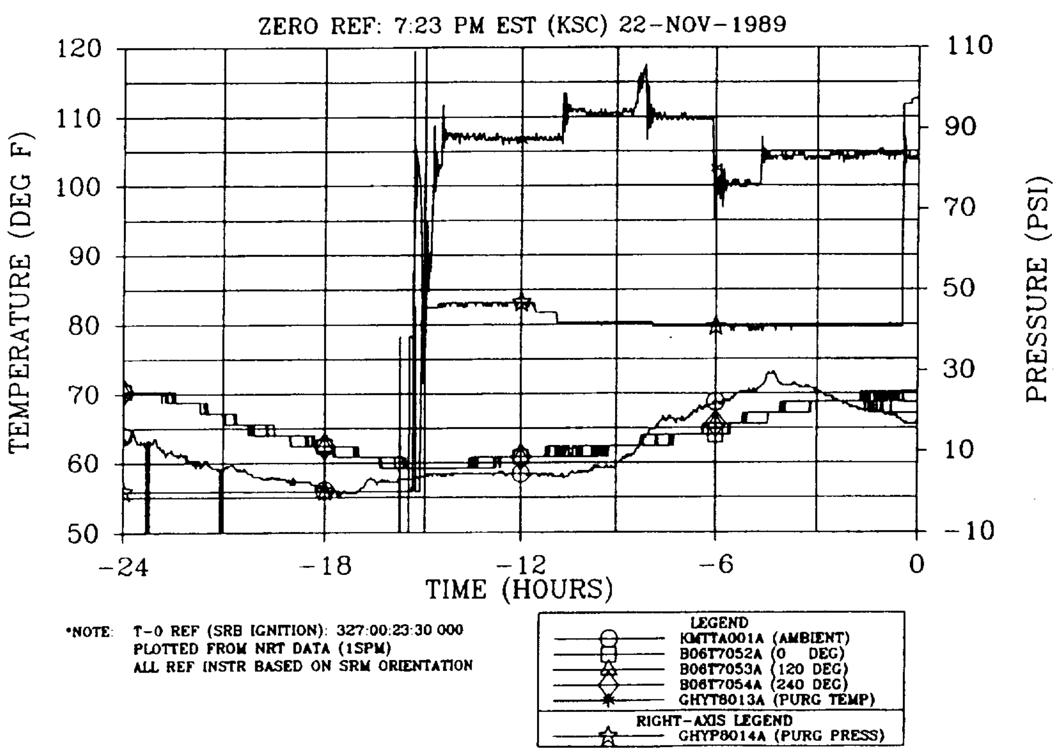


Figure 4.8-86. LH SRM Nozzle Region Temperature at Station 1950.0 (overlaid with ambient)

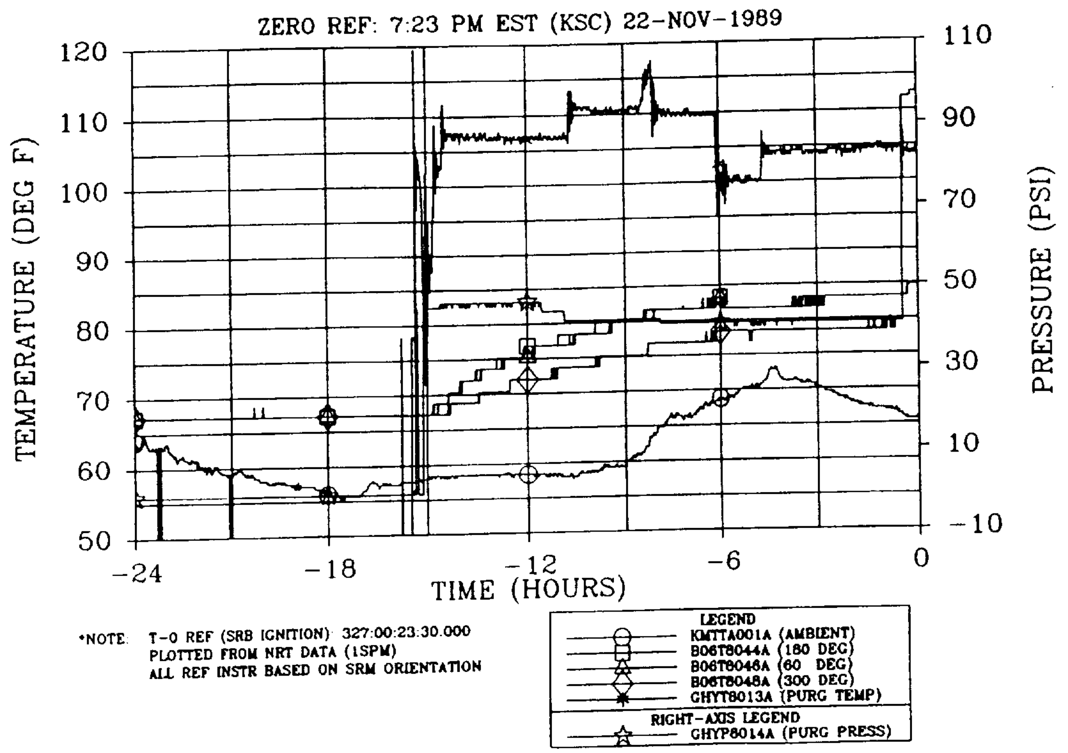


Figure 4.8-87. RH SRM Nozzle Region Temperature at Station 1845.0 (overlaid with ambient)

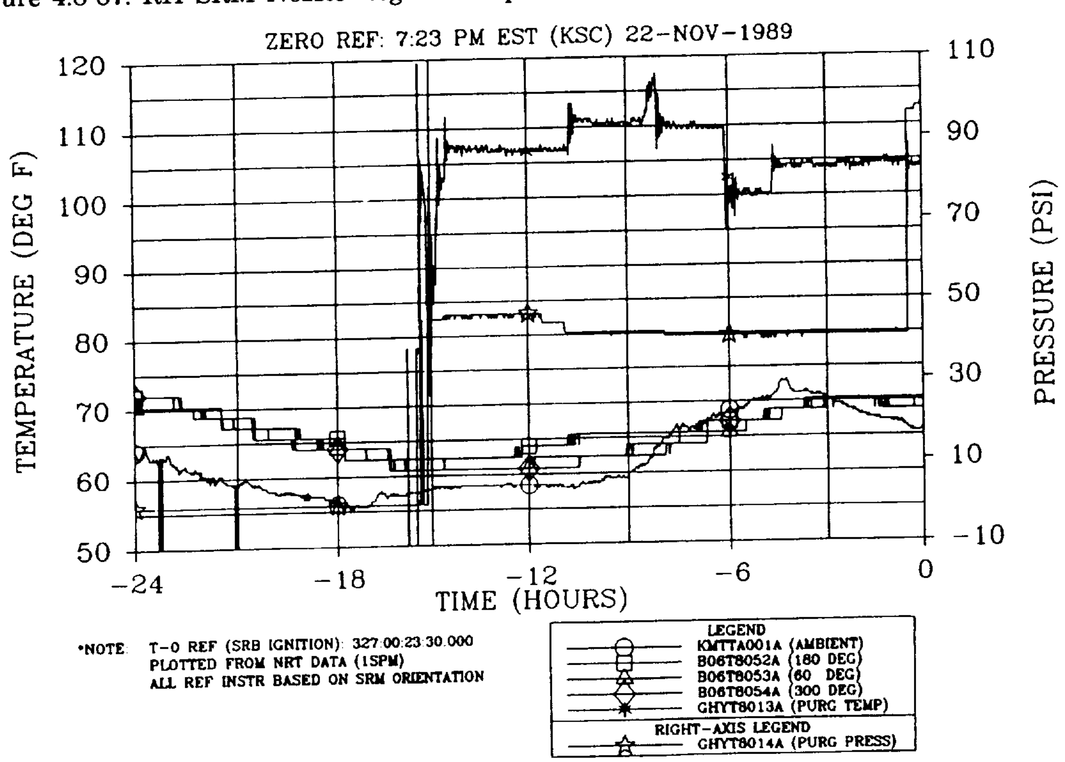


Figure 4.8-88. RH SRM Nozzle Region Temperature at Station 1950.0 (overlaid with ambient)

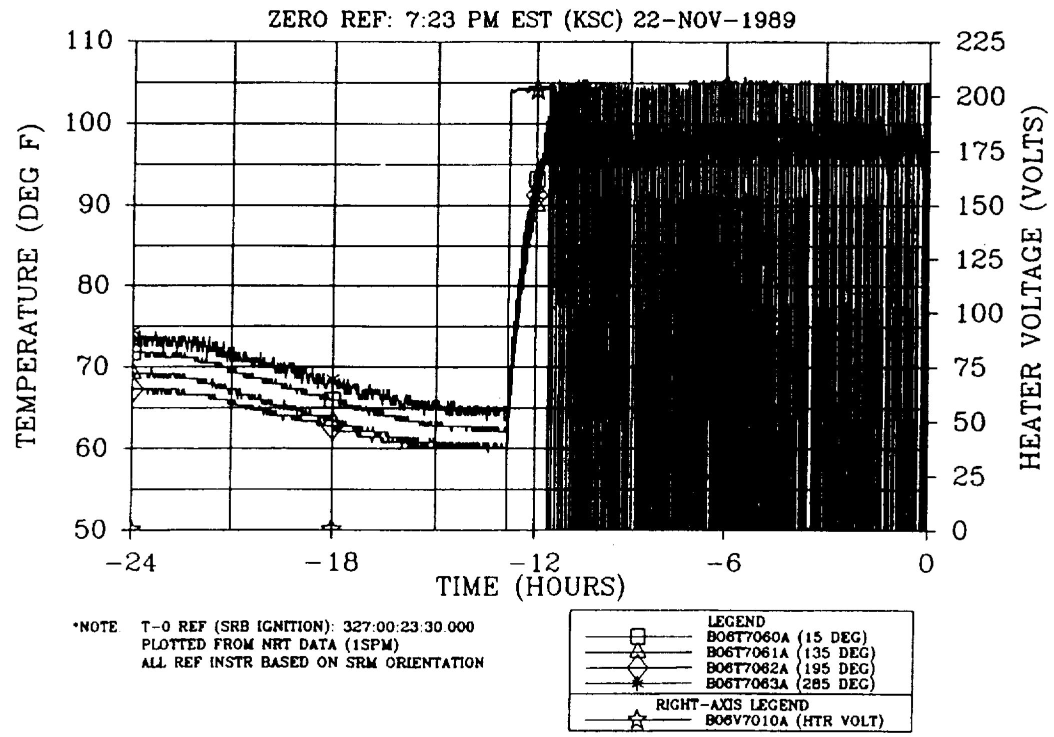


Figure 4.8-89. LH SRM Forward Field Joint Temperature (overlaid with heater voltage)

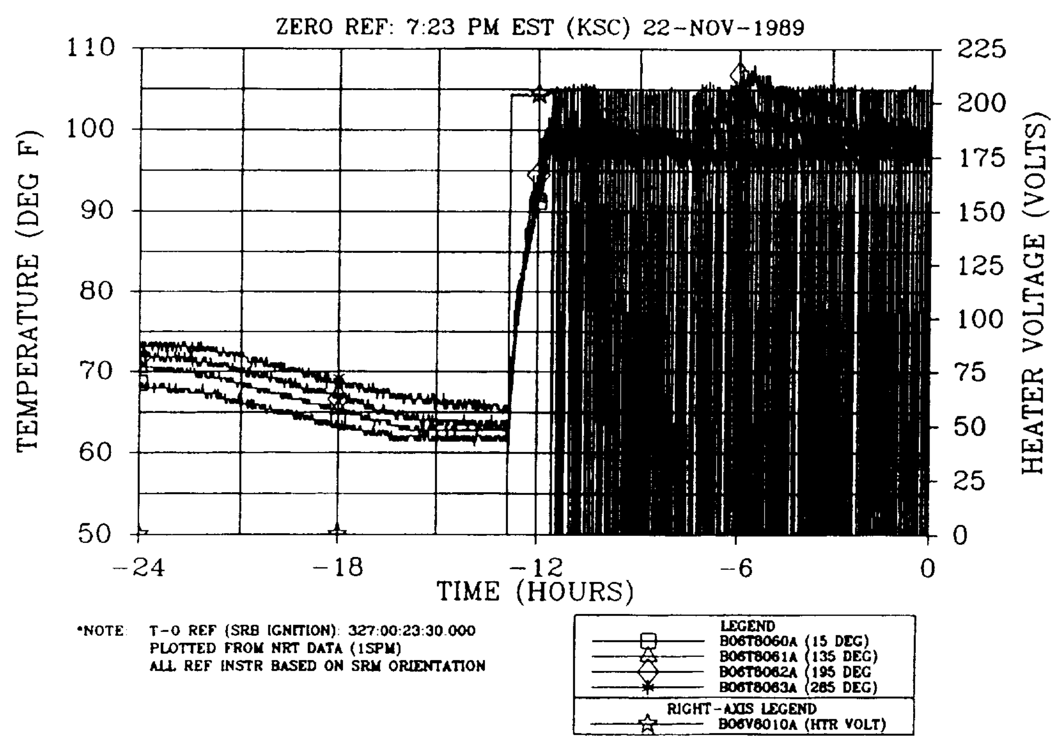


Figure 4.8-90. RH SRM Forward Field Joint Temperature (overlaid with heater voltage)

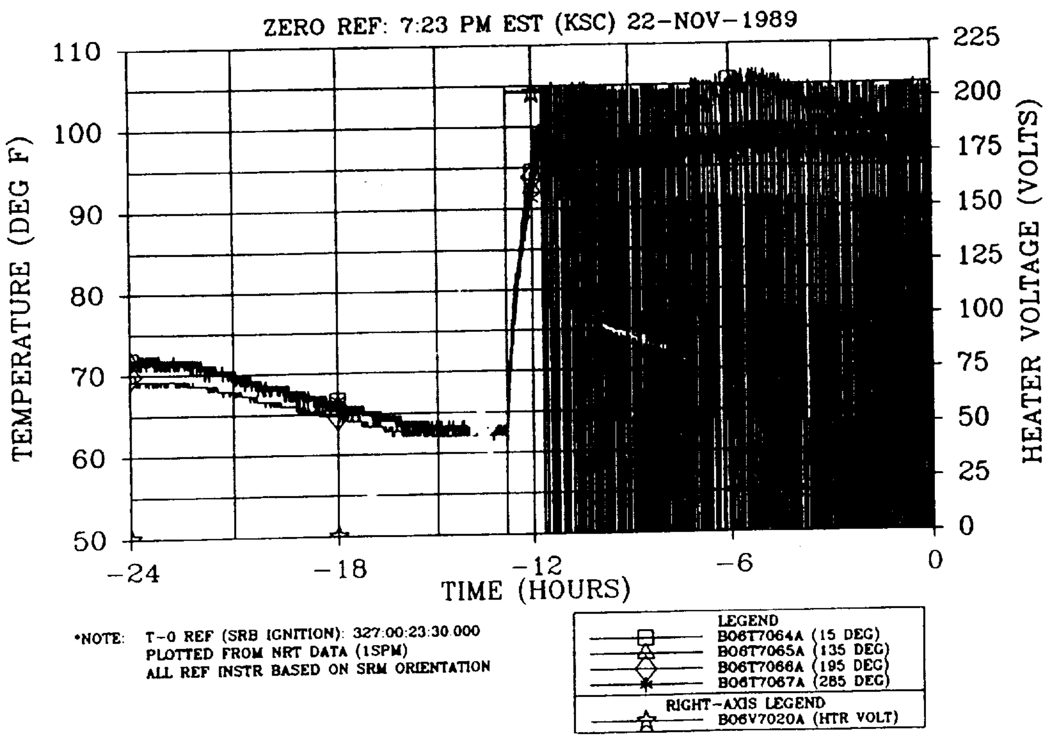


Figure 4.8-91. LH SRM Center Field Joint Temperature (overlaid with heater voltage)

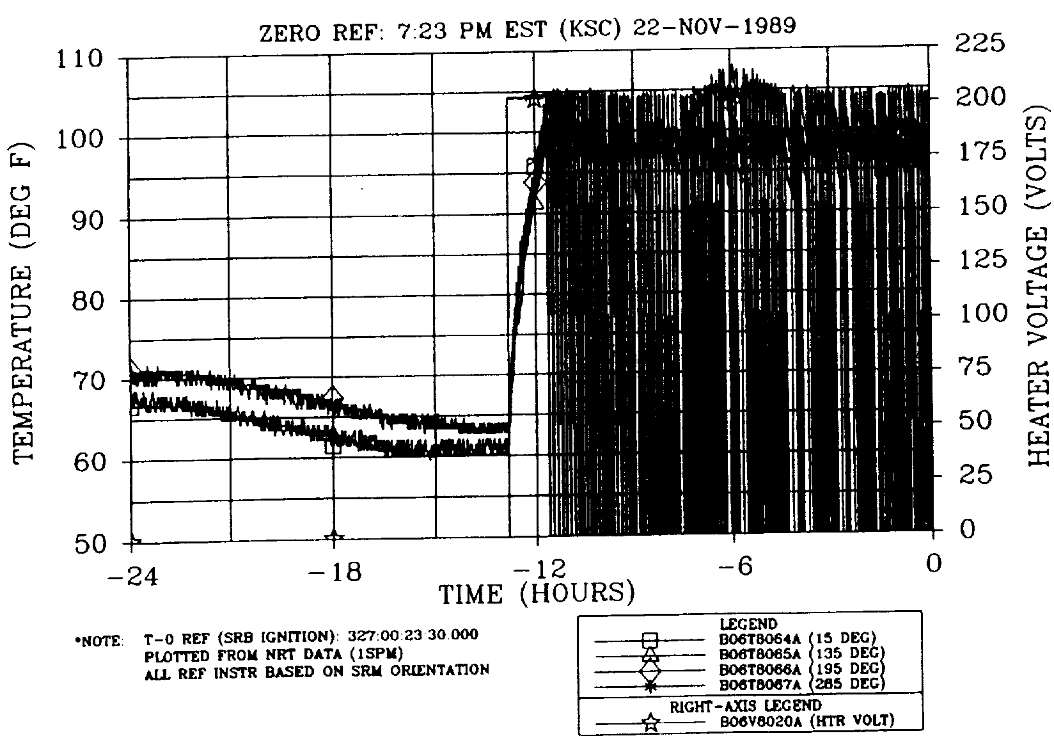


Figure 4.8-92. RH SRM Center Field Joint Temperature (overlaid with heater voltage)

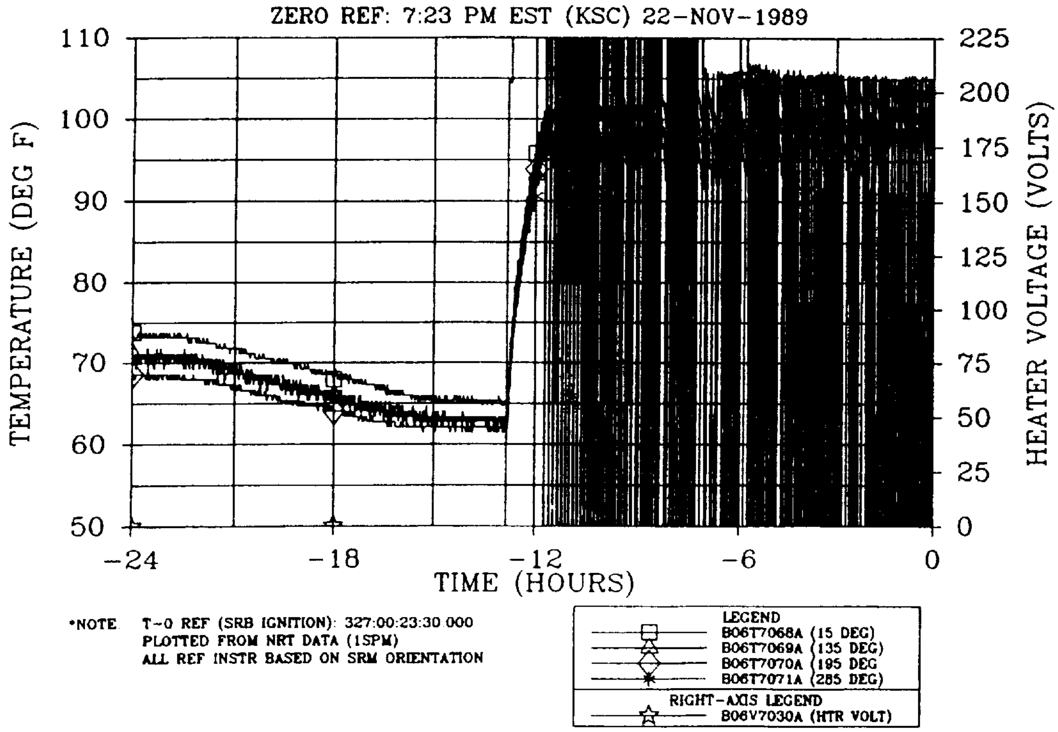


Figure 4.8-93. LH SRM Aft Field Joint Temperature (overlaid with heater voltage)

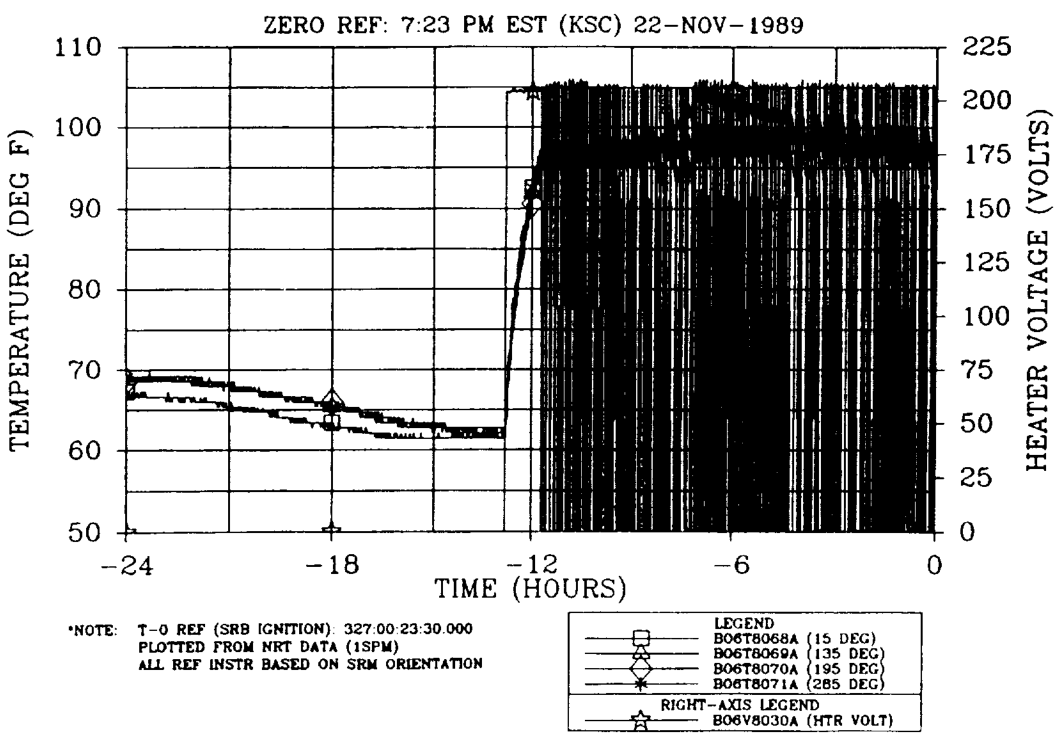


Figure 4.8-94. RH SRM Aft Field Joint Temperature (overlaid with heater voltage)

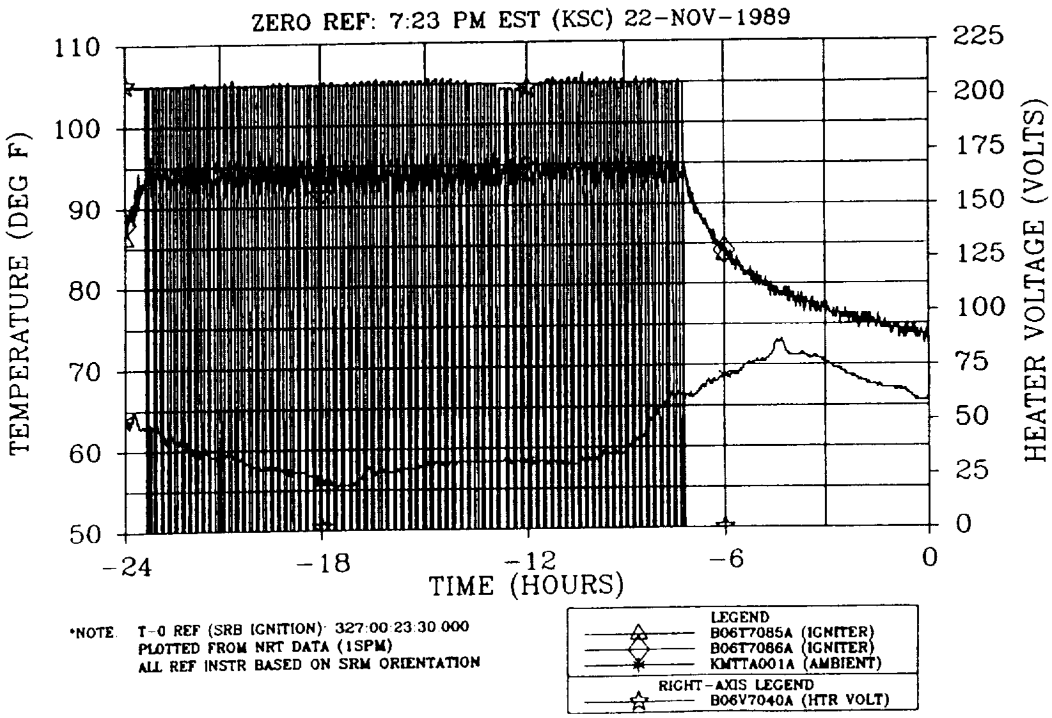


Figure 4.8-95. LH SRM Igniter Field Joint Temperature (overlaid with heater voltage)

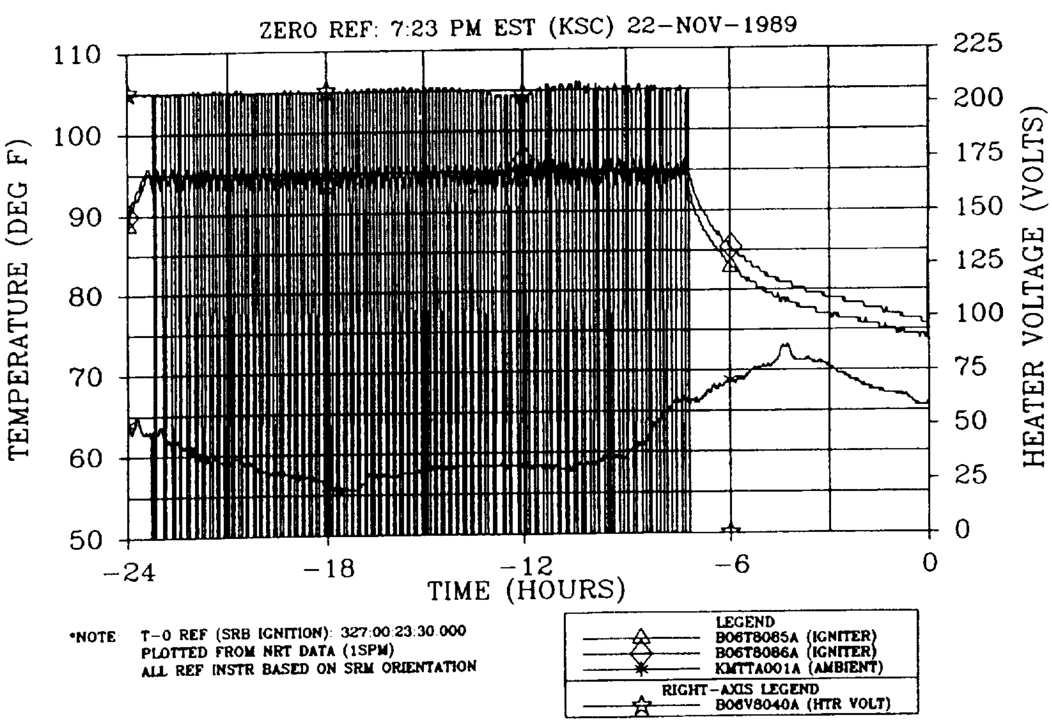


Figure 4.8-96. RH SRM Igniter Joint Temperature (overlaid with heater voltage)

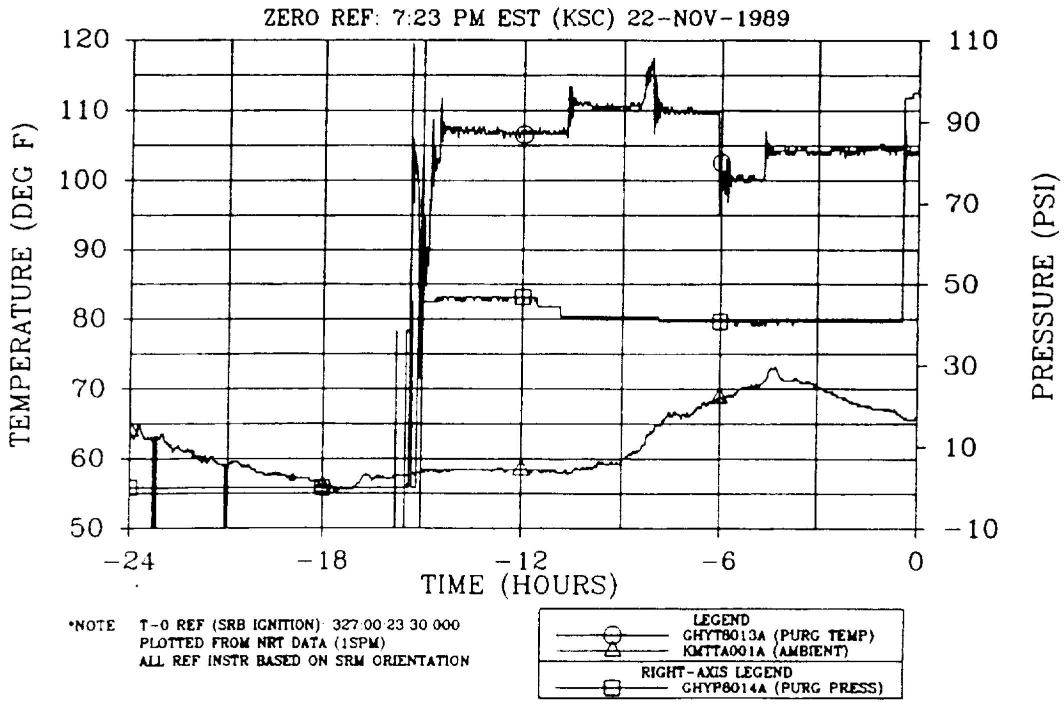


Figure 4.8-97. Aft Skirt Purge Temperature and Pressure (overlaid with ambient)

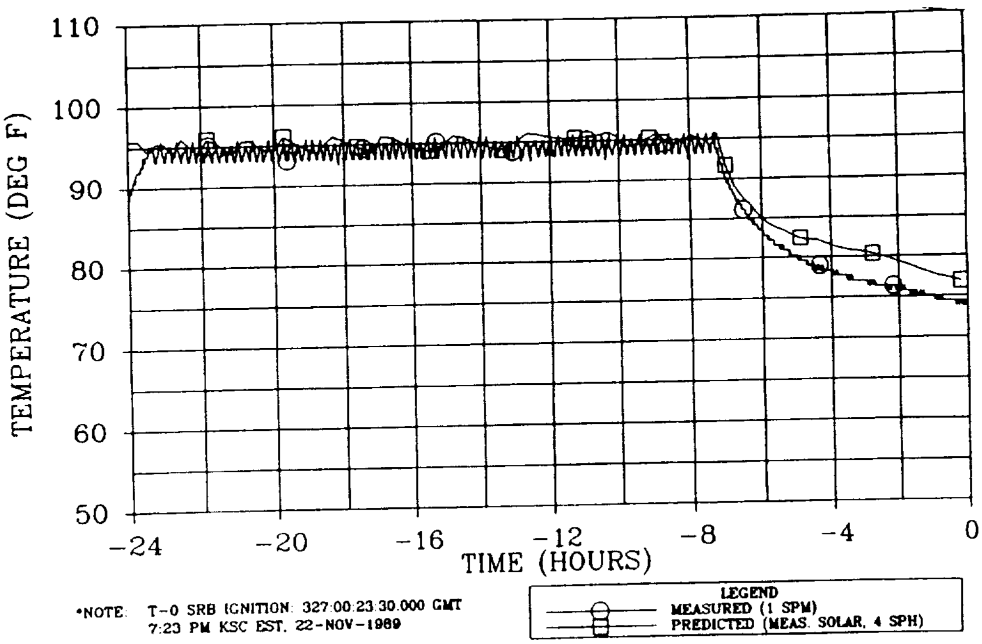


Figure 4.8-98. LH SRM Igniter Joint Temperatures--Measured Versus Postflight Prediction (B06T7085A, igniter)

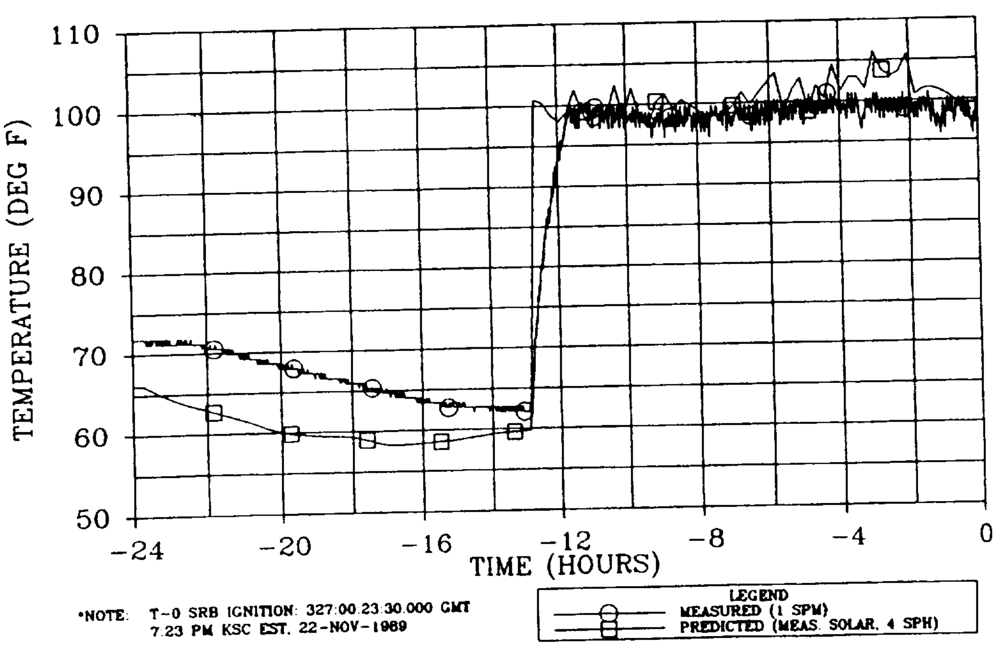


Figure 4.8-99. LH SRM Forward Field Joint Temperature--Measured Versus Postflight Prediction (B06T7060A, 15 deg)

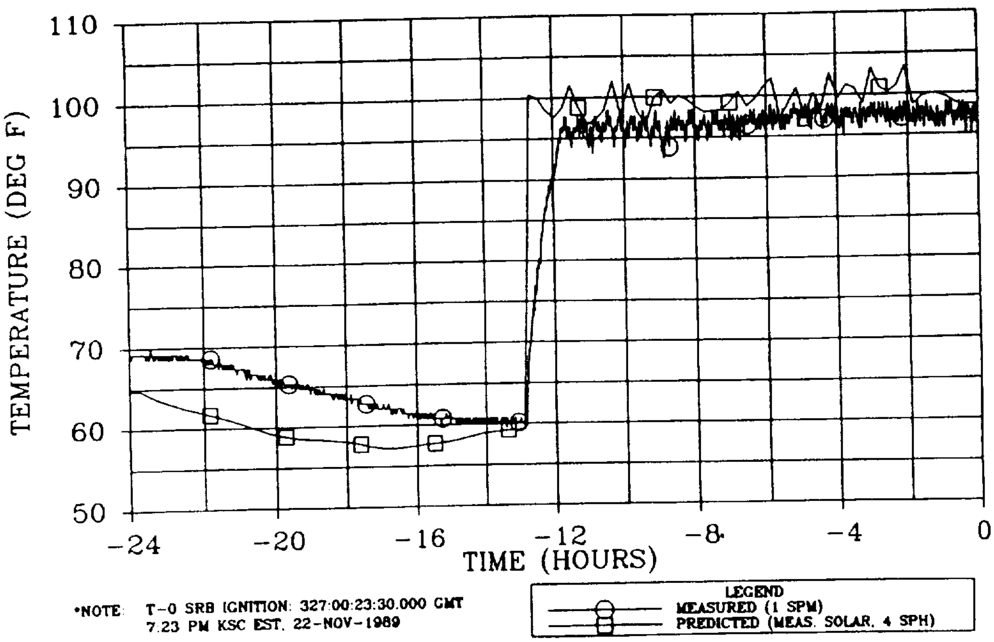


Figure 4.8-100. LH SRM Forward Field Joint Temperature--Measured Versus Postflight Prediction (B06T7061A, 135 deg)

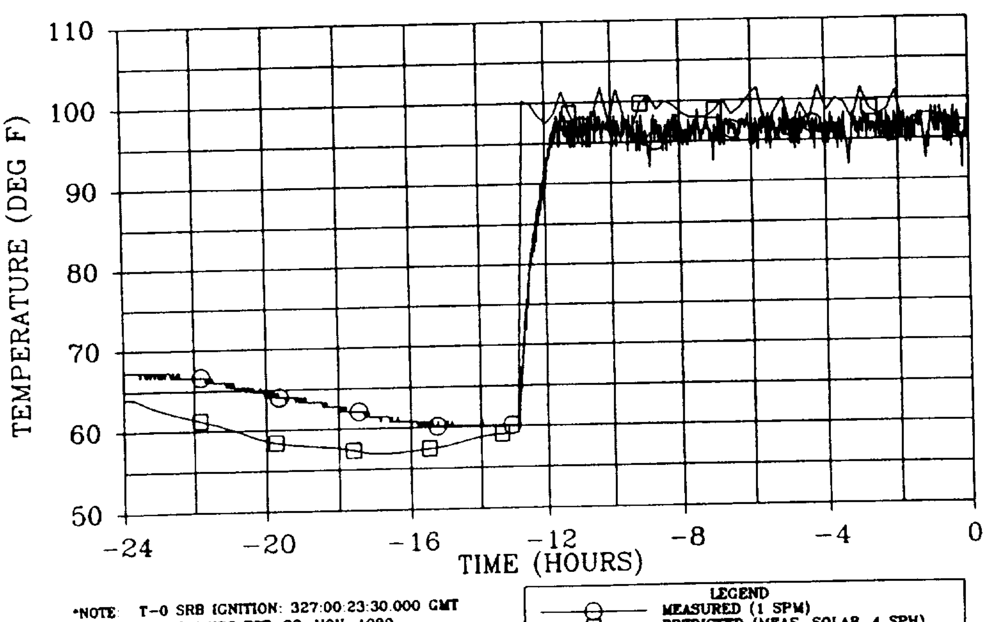


Figure 4.8-101. LH SRM Forward Field Joint Temperature--Measured Versus Postflight Prediction (B06T7062A, 195 deg)

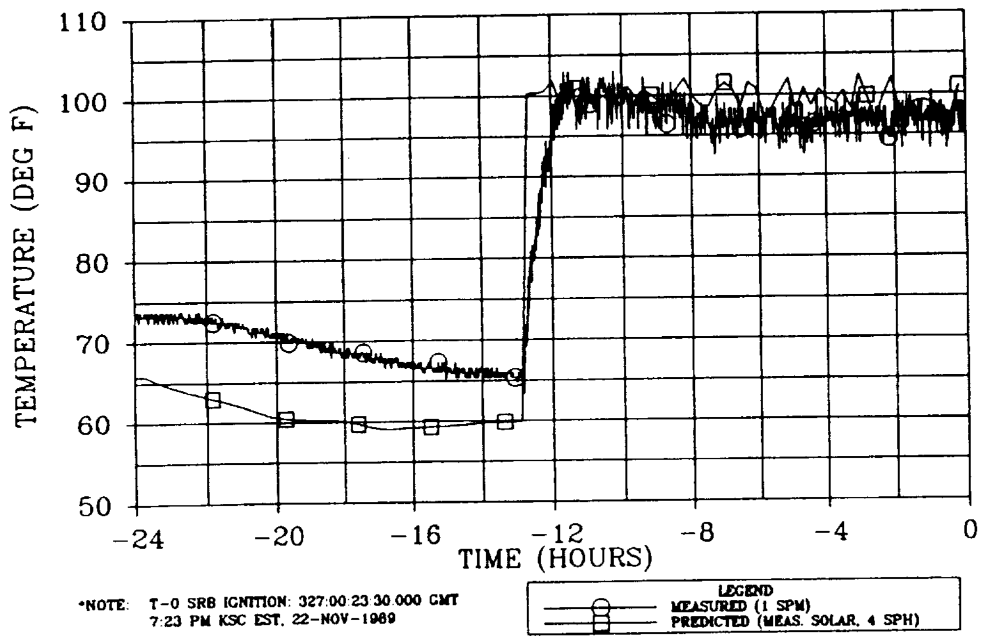


Figure 4.8-102. RH SRM Forward Field Joint Temperature--Measured Versus Postflight Prediction (B06T8063A, 285 deg)

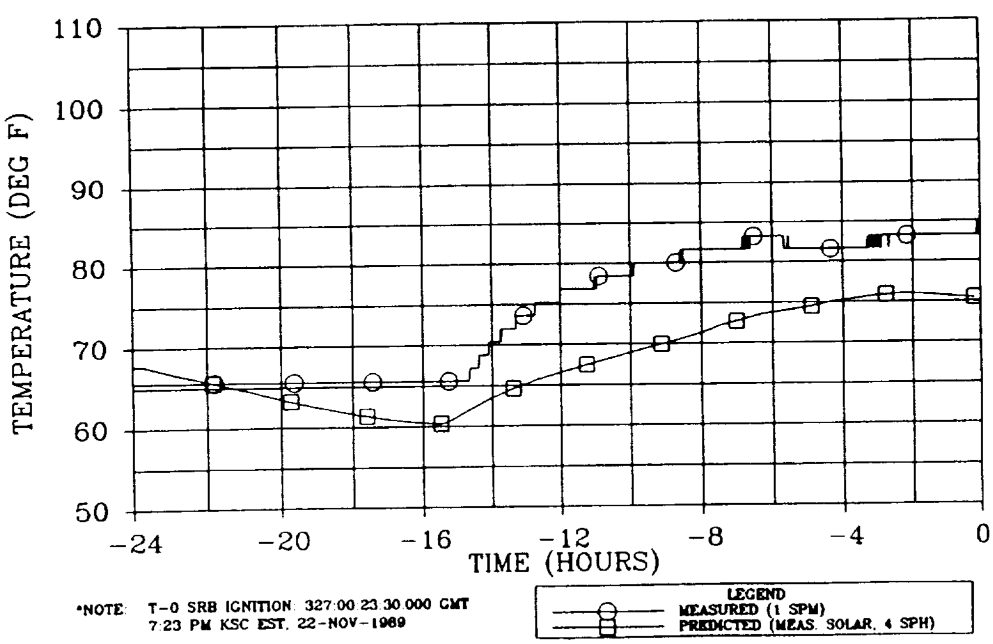


Figure 4.8-103. RH SRM Case-to-Nozzle Joint Temperature--Measured Versus Postflight Prediction (B06T8049A, 180 deg)

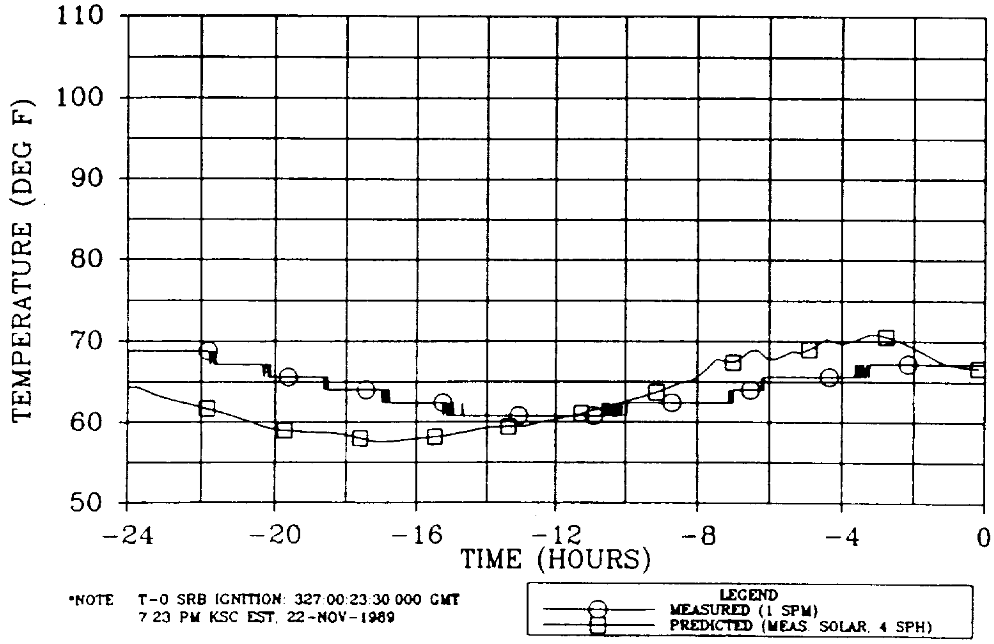


Figure 4.8-104. LH SRM Systems Tunnel Bondline Temperature--Measured Versus Postflight Prediction (B06T7031A, aft)

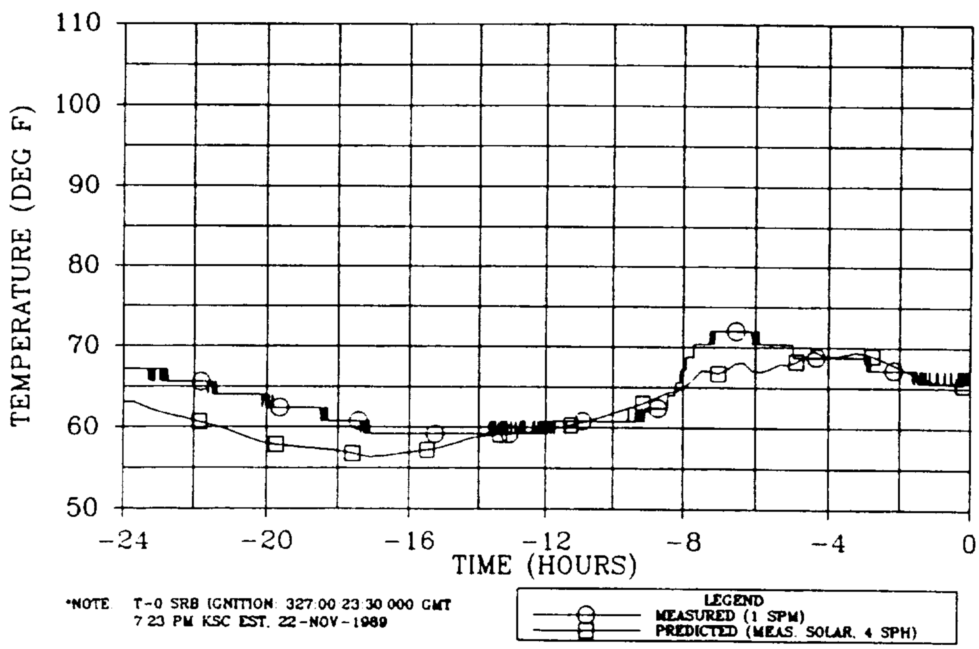


Figure 4.8-105. RH SRM Case Acreage Temperature at Station 931.5--Measured Versus Postflight Prediction (B06T8010A, 135 deg)

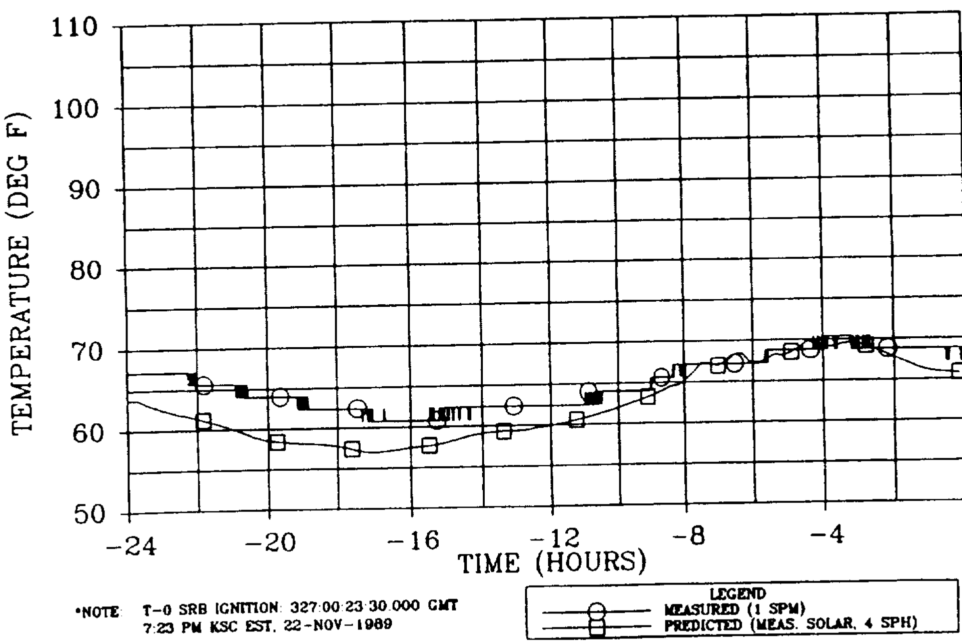


Figure 4.8-106. RH SRM Case Acreage Temperature at Station 931.5--Measured Versus Postflight Prediction (B06T8011A, 45 deg)

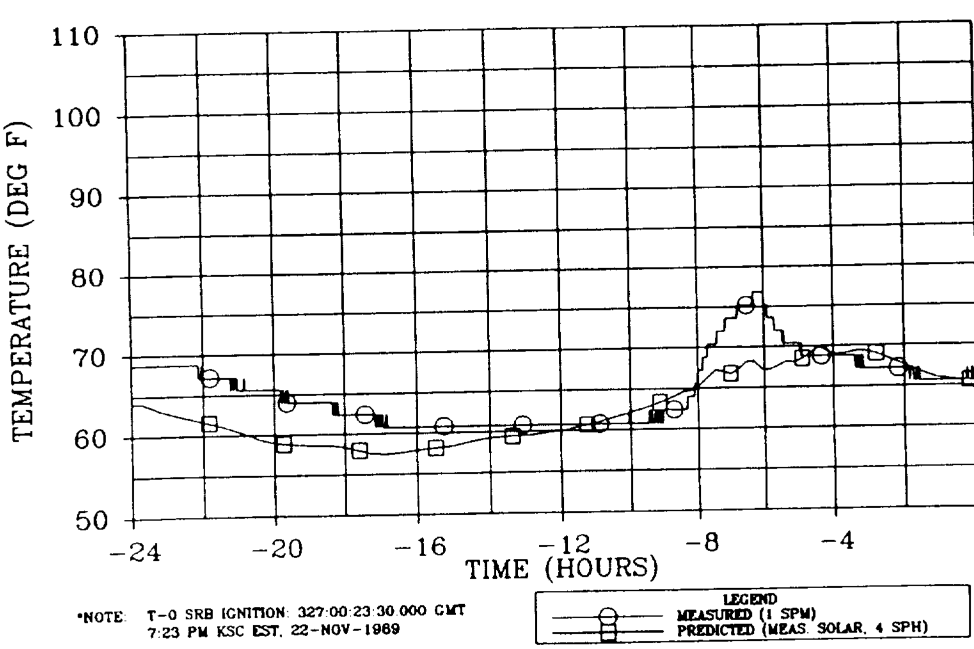


Figure 4.8-107. RH SRM Case Acreage Temperature at Station 931.5--Measured Versus Postflight Prediction (B06T8012A, 215 deg)

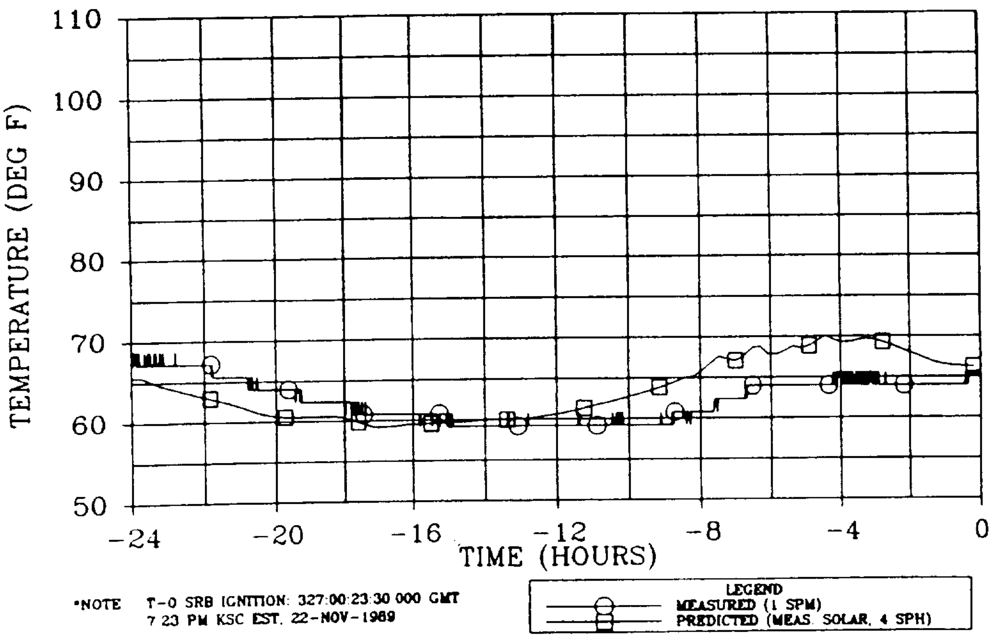


Figure 4.8-108. RH SRM Case Acreage Temperature at Station 931.5--Measured Versus Postflight Prediction (B06T8013A, 270 deg)

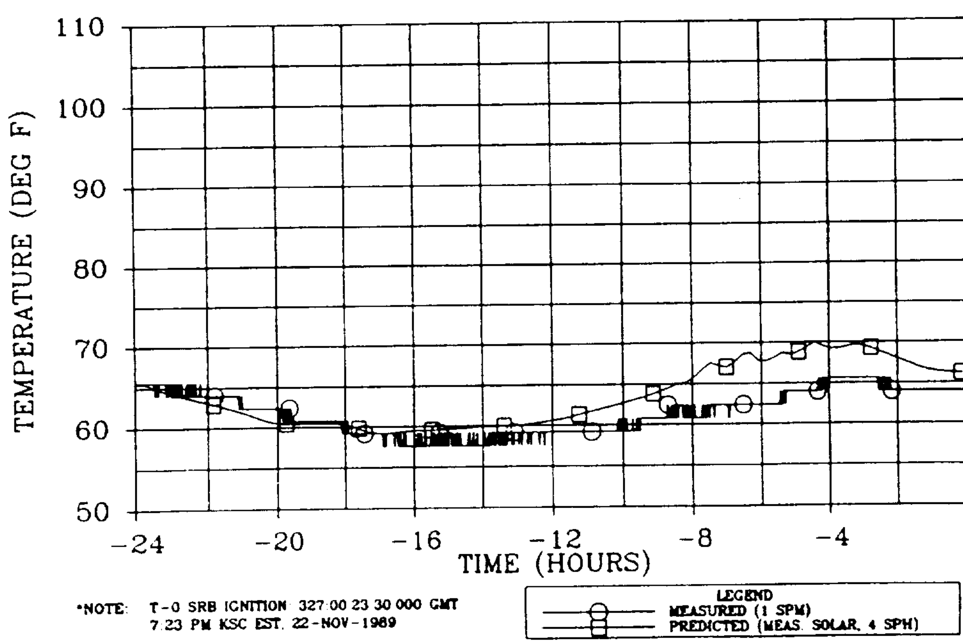


Figure 4.8-109. RH SRM Case Acreage Temperature at Station 931.5--Measured Versus Postflight Prediction (B06T8014A, 325 deg)

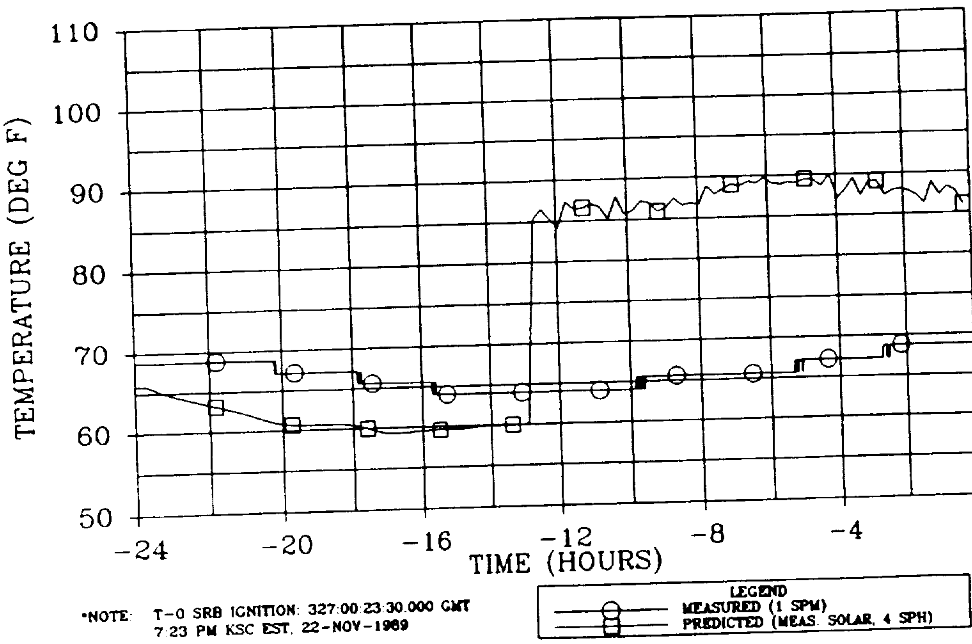


Figure 4.8-110. LH SRM ET Attach Region Temperature at Station 1511.0--Measured Versus Postflight Prediction (B06T7027A, 274 deg)

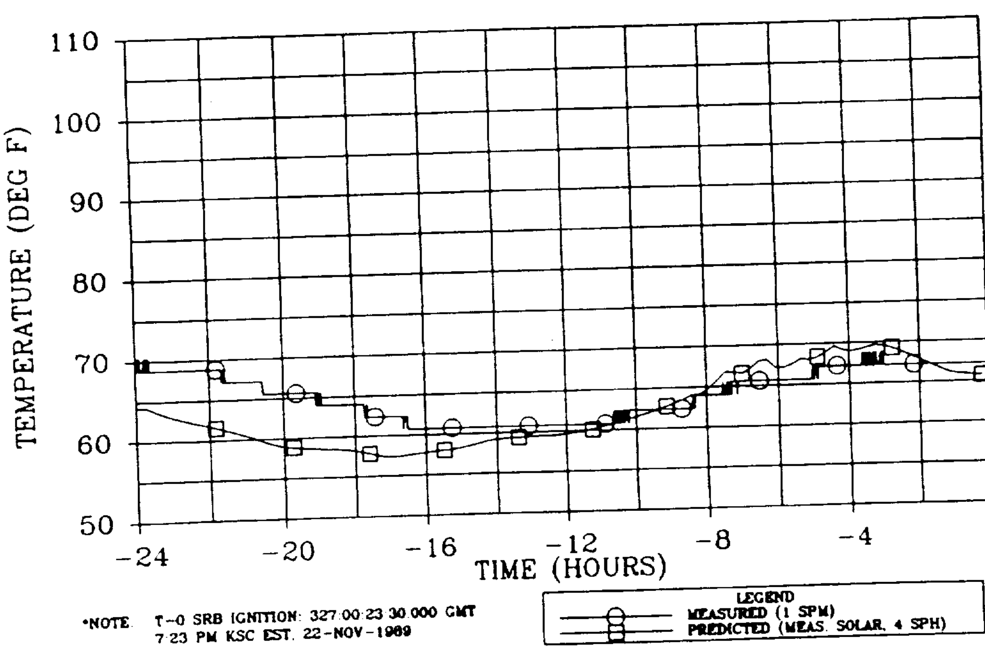


Figure 4.8-111. RH SRM Aft Factory Joint Temperature at Station 1701.9--Measured Versus Postflight Prediction (B06T8032A, 150 deg)

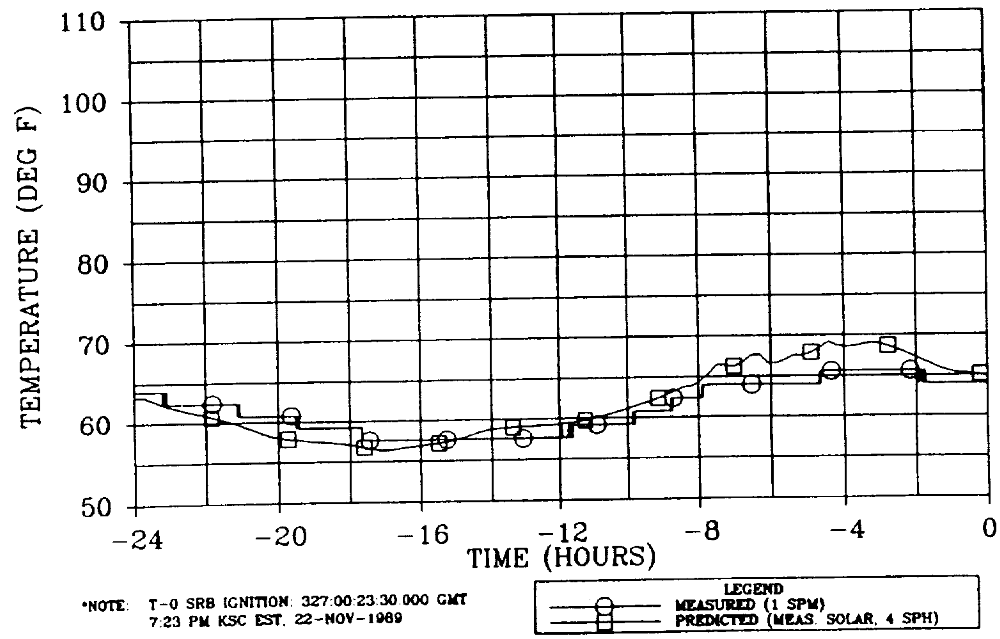


Figure 4.8-112. RH SRM Aft Factory Joint Temperature at Station 1701.9--Measured Versus Postflight Prediction (B06T8033A, 30 deg)

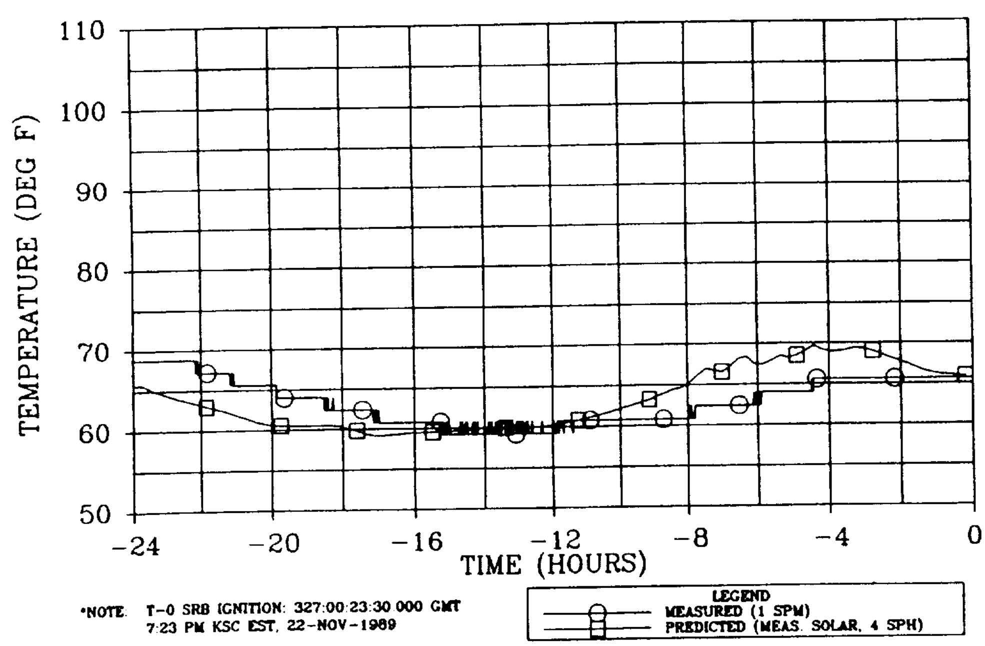


Figure 4.8-113. RH SRM Aft Factory Joint Temperature at Station 1701.9--Measured Versus Postflight Prediction (B06T8034A, 270 deg)

joint regions. In the future, modeling improvements (environment and detail) need to be made in these regions.

Figure 4.8-114 shows the postflight FBMBT prediction created from reconstructed ambient temperature and aft skirt purge data. The prediction is not shown compared to the data.

4.8.3.7 Prelaunch Hardware Anomalies. There were no prelaunch hardware anomalies.

4.8.4 Conclusions and Recommendations

A summary of these recommendations was previously presented in Section 3.3. A more detailed explanation is provided here.

4.8.4.1 Postflight Hardware Inspection. Based on the quick-look external inspection, the SRM TPS performed adequately on STS-33R. No unexpected heating effects were noted.

4.8.4.2 Debris. No SRM violations of NSTS debris criteria were noted. The problem of losing the TPS cork caps covering the GEI cables due to poor cork bonds appears to have been alleviated. The K5NA closeout in place of the cork caps is performing excellently and as expected. All TPS cork pieces (generally small) are due to nozzle severance debris and/or splashdown loads and debris.

Stencils marking the GEI MSID locations have replaced the original labels with epoxy closeout. This will eliminate epoxy closeout as a debris concern.

During STS-34R ascent film review, indications suggested that there are debris particles coming out of the SRM nozzle prior to separation. The likelihood of these being chunks of propellant and/or insulation is still under investigation.

4.8.4.3 GEI Prediction. Additional model enhancement is recommended for certain motor regions in order to improve predictions. It should be noted, however, that the attainment of actual solar radiation data for recent STS flights has improved postflight predictions significantly. Submodel development effort for the areas of the ET attach ring, field joint, factory joint, systems tunnel, igniter, and nozzle regions is anticipated. These tasks would be encompassed by the global model. It is also recommended that all these models, including the 3-D SRM model, be made available for use at MSFC. This would allow Thiokol thermal personnel the opportunity to support launch countdowns at the HOSC with real-time PMBT, GEI, and component

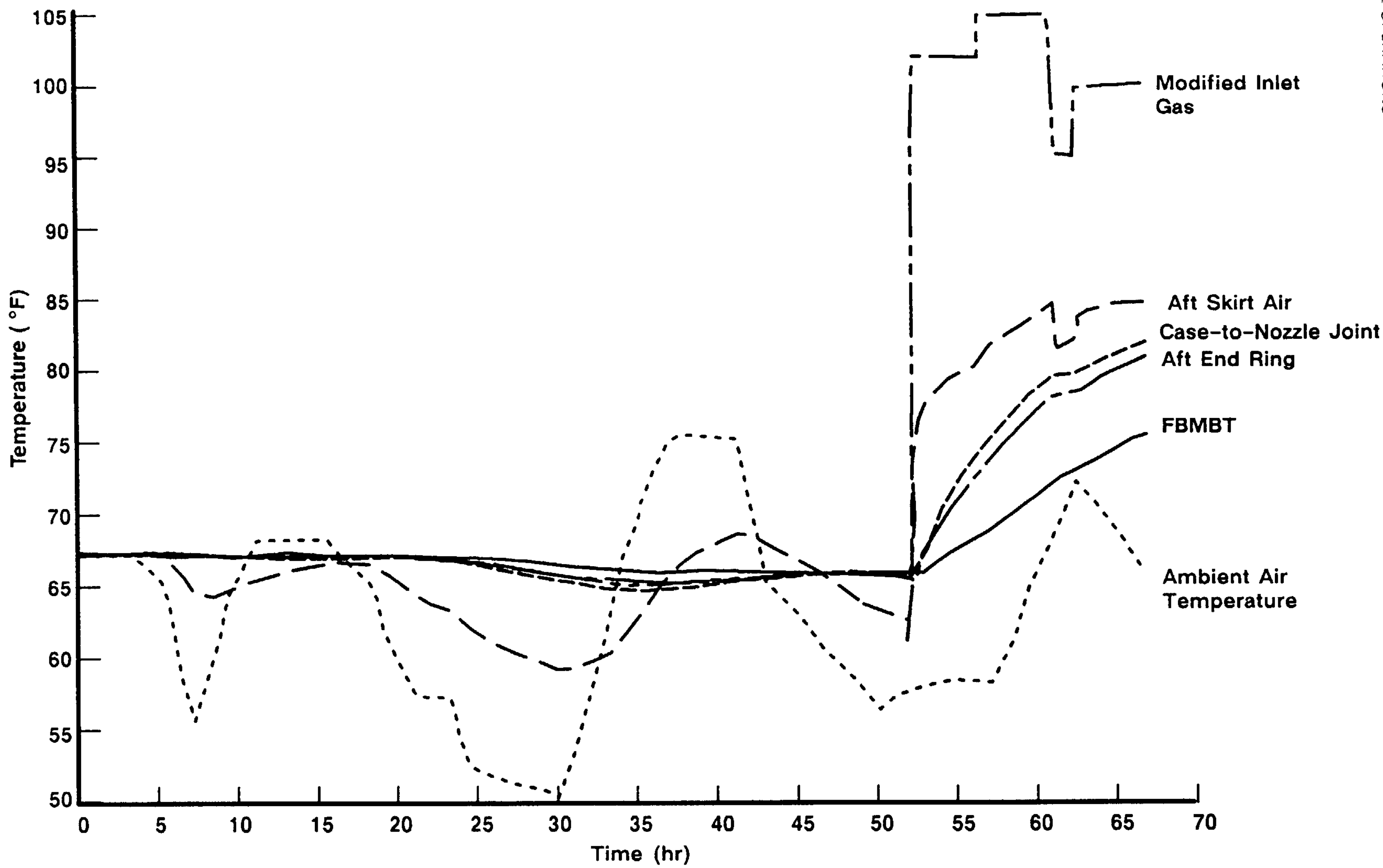


Figure 4.8-114. Aft End Temperature Prediction (mg = 35 lbm/min, hc = 2.0 $Btu/hr/ft^2/°F$)

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prediction updates. This would also allow MSFC thermal personnel the same modeling capabilities.

4.8.4.4 GEI Accuracy. Gage range has been reduced on all of the joint heater sensors, resulting in better data resolution. It is recommended that the data collection accuracy of all GEI be increased by reducing the gage range and increasing the digital word length. The real fidelity of the KSC GSE could then be quantified and conceivably replaced if determined to be inadequate.

4.8.4.5 Local Chilling. Based on data from STS-28, STS-29R, and STS-30R local cooling does occur. Due to dissimilar ambient environments on launch day and the day prior to launch, it was not possible to determine the local chilling for this flight. It is recommended that a method be developed to accurately quantify the chill effect.

4.8.4.6 Infrared Measurements. STI data continue to be much more reliable than IR gun measurements. Comparisons with GEI are within acceptable margins for STI data but are questionable and unpredictable for IR gun data. Future efforts should be made in specifying locations for additional stationary STI cameras to assist in the eventual replacement of the outboard GEI. (Inboard GEI will need to be maintained since the STI cannot reach these blind regions.)

4.8.4.7 Ice/Debris Team Support. Thiokol personnel who support the ice/debris team from flight to flight should be maintained.

4.8.4.8 SRM Hardware Thermal Assessment. The SRM TPS design, from a thermal perspective, continues to suggest that the worst-case flight design environments of IVBC-3 and SRB reentry are for the most part overly conservative. An exception to this is the environment in the nozzle base region during reentry, when excessive nozzle flame heating and hydrazine fires are present. (See STS-29R final report, TWR-17542, Vol I). USBI is in the process of obtaining updated thermal environments for the base region. However, a followthrough needs to be made concerning the request.

4.9 MEASUREMENT SYSTEM PERFORMANCE--DEVELOPMENT FLIGHT INSTRUMENTATION (DFI) (FEWG report Paragraph 2.9.5)

Motor set 360L007 did not have any DFI installed. This section is reserved pending any future motors that incorporate DFI.

4.10 MEASUREMENT SYSTEM PERFORMANCE (FEWG report Paragraph 2.9.7)

4.10.1 Instrumentation Summary

Table 4.10-1 shows the location and amount of instrumentation for 360L007. Note that the igniter heater sensors are classified as GEI, whereas the field joint heater sensors are listed under a separate category. The OFI consists of the three OPTs which are used to determine the SRB separation time and provide the ballistic performance assessment.

Table 4.10-1. 360L007 (STS-33R) Instrumentation

	LH Motor			RH Motor			
	OFI	GEI	Heaters	OFI	GEI	Heaters	Total
Pressure	3	--	--	3	--	--	6
Temperature	--	54*	12	--	54*	12	132

*Includes igniter heater sensors

4.10.2 GEI/OFI Performance

The GEI instrumentation on flight set 360L007 consisted of 108 temperature sensors, resistance temperature detectors (RTD) which monitor motor case temperature while the motor is on the pad. OFI consists of three OPTs on each forward dome. All GEI gages were functioning and all were within the allowable variation before launch. When the field joints were powered up, the LH aft heater voltage read nominal (204 V) for about 8 minutes, then jumped to 290 V. The voltage again returned to normal following igniter heater deactivation. No deviation in the heater current was observed during this time period. A bad solder joint was later dispositioned to be the problem in problem report No. PV6-147103. Troubleshooting showed the solder connections in the voltage transducer to be broken. The bad joints were resoldered and the system retested; the system is now functional. Upon further investigation, it was discovered that the solder joint in question was within the power supply of the instrument itself rather than in the electrical supply line as initially reported in the problem report. It is suspected that the momentary interruption of power (as the igniter heaters were shut down) restored continuity in the solder joint and returned the heater voltage to a nominal reading (Figure 4.10-1). (All GEI are disconnected by breakaway umbilicals at

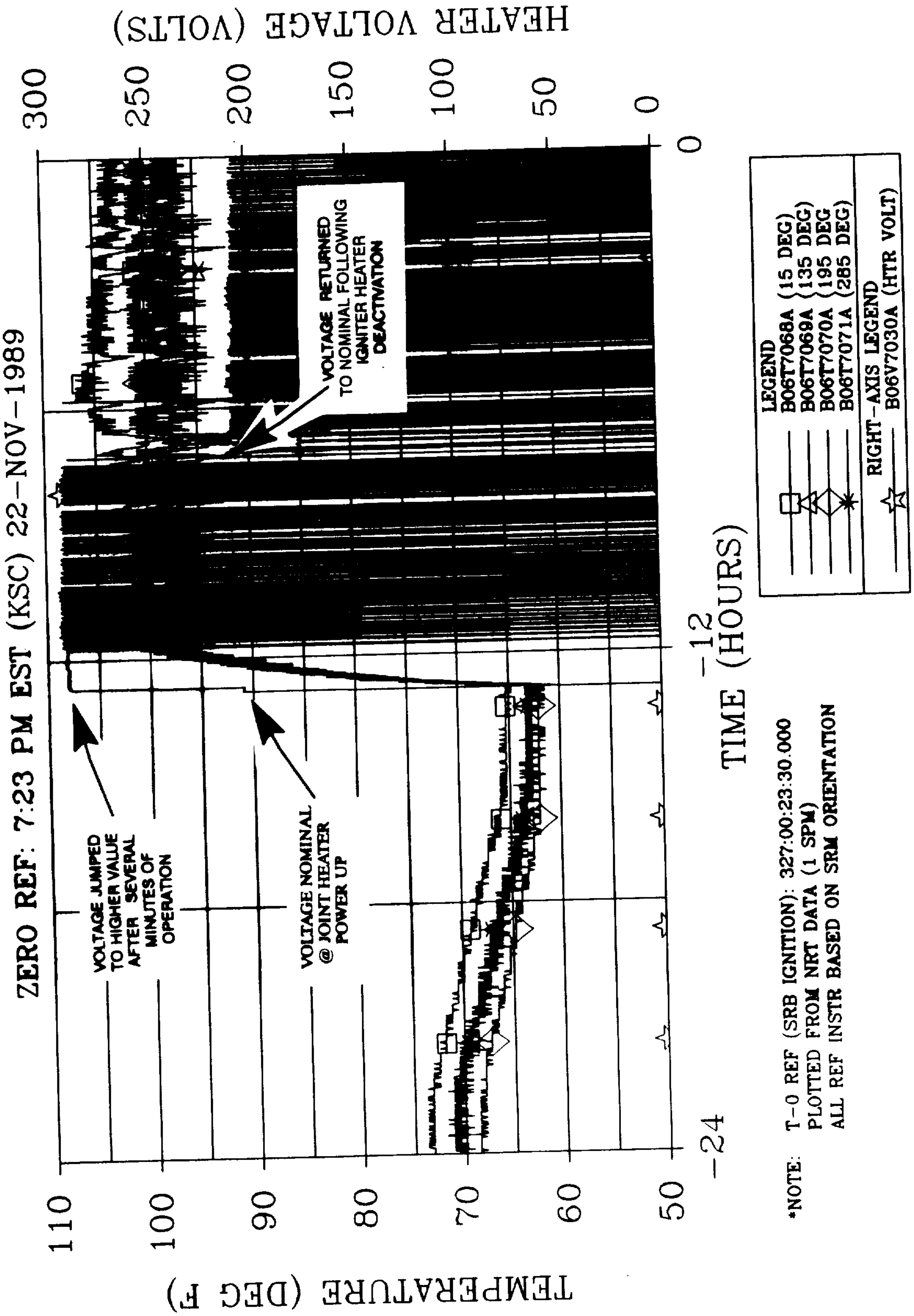

Figure 4.10-1. LH SRM Aft Field Joint Temperature (overlaid with heater voltage)

SRB ignition and are not operative during flight.) Tables 4.10-2 and 4.10-3 are the GEI instrumentation lists and include gages which consistently read differently from surrounding gages. Figures 4.8-6 and 4.8-8 through 4.8-10 show GEI/OFI locations.

The OFI consists of three OPTs on each forward dome. The results of the 75 percent calibration (performed at T-1.5 hr) verified readings were well within the 740 to 804-psia allowable range and are listed in Table 4.10-4. B47P2302C was adjusted prior to the 75 percent calibration sequence to reflect a more nominal value. The transducer provided marginal readings at the beginning of the countdown due to the use of the generic launch processing system calibration offset of -11.3 psi rather than the actual OPT offset of -4.1 psi.

4.10.3 Heater Sensor Performance

Evaluation of the field joint heaters and heater sensor performance was discussed previously in Section 4.8.3. Table 4.10-5 and Figure 4.8-7 list the joint heater sensors and show the gage locations, respectively.

4.10.4 S&A Rotation Times

Table 4.10-6 includes the arm and safe delta times for the S&A functional test performed prior to the 360L007 (STS-33R) countdown. There was some concern that the S&As may perform slower than expected when a delayed rotation time of 2.6 sec was revealed during testing, causing an IPR (No. 33RV-0165) to be written. To close that IPR an additional S&A functionality test was performed. Table 4.10-7 lists the arm and safe times during the actual launch sequence (at T-5 minutes). All values are less that 2.0 sec.

4.11 RSRM HARDWARE ASSESSMENT (FEWG report Paragraph 2.11.2)

4.11.1 Insulation Performance

4.11.1.1 Summary. No gas paths through the case-to-nozzle joint polysulfide adhesive or any other anomalous joint conditions were identified. The internal insulation in all six of the case field joints also performed as designed, with no anomalous conditions. There were no recordable clevis edge separations (over 0.1 in.). No evidence of hot gas penetration through any of the acreage insulation or severe erosion patterns were identified. A complete insulation performance evaluation is in Volume III of this report.

Table 4.10-2. GEI List--360L007A (LH)

Instrument No.	Location (deg)	Station	Range (°F)	Case Location
B06T7003A	270	534.5	±200	Forward segment
B06T7004A	45	694.5	±200	Forward segment
B06T7005A	135	694.5	±200	Forward segment
B06T7006A	325	694.5	±200	Forward segment
B06T7007A	270	694.5	±200	Forward segment
B06T7008A	215	694.5	±200	Forward segment
B06T7009A	90	778.98	±200	Forward segment (systems tunnel)
B06T7010A	45	931.48	±200	Forward center segment
B06T7011A	135	931.48	±200	Forward center segment
B06T7012A	325	931.48	±200	Forward center segment
B06T7013A	270	931.48	±200	Forward center segment
B06T7014A	215	931.48	±200	Forward center segment
B06T7015A	45	1091.48	±200	Forward center segment
B06T7016A	135	1091.48	±200	Forward center segment
B06T7017A	325	1091.48	±200	Forward center segment
B06T7018A	270	1091.48	±200	Forward center segment
B06T7019A	215	1091.48	±200	Forward center segment
B06T7020A	90	1258.98	±200	Aft center segment (systems tunnel)
B06T7021A	45	1411.48	±200	Aft center segment
B06T7022A	135	1411.48	±200	Aft center segment
B06T7023A	325	1411.48	±200	Aft center segment
B06T7024A	270	1411.48	±200	Aft center segment
B06T7025A	215	1411.48	±200	Aft center segment
B06T7026A	220	1511	±200	ET attach ring
B06T7027A	274	1511	±200	ET attach ring
B06T7028A	320	1511	±200	ET attach ring
B06T7029A	45	1535	±200	Aft segment
B06T7030A	135	1535	±200	Aft segment
B06T7031A	90	1565	±200	Aft segment (systems tunnel)
B06T7032A	30	1701.86	±200	Aft segment
B06T7033A	150	1701.86	±200	Aft segment
B06T7034A	270	1701.86	±200	Aft segment
B06T7035A	45	1751.5	±200	Aft segment
B06T7036A	135	1751.5	±200	Aft segment
B06T7037A	325	1751.5	±200	Aft segment
B06T7038A	270	1751.5	±200	Aft segment
B06T7039A	215	1751.5	±200	Aft segment
B06T7040A	30	1821	±200	Aft segment
B06T7041A	150	1821	±200	Aft segment
B06T7042A	270	1821	±200	Aft segment
B06T7043A	0	1847	±200	Flex bearing
B06T7044A	0	1845	±200	Nozzle throat
B06T7045A	120	1847	±200	Flex bearing
B06T7046A	120	1845	±200	Nozzle throat
B06T7047A	240	1847	±200	Flex bearing
B06T7048A	240	1845	±200	Nozzle throat

Table 4.10-2. GEI List--360L007A (LH) (Cont)

Instrument No.	Location (deg)	Station	Range (°F)	Case Location
B06T7049A	0	1876.6	±200	Case-to-nozzle joint
B06T7050A	120	1876.6	±200	Case-to-nozzle joint
B06T7051A	240	1876.6	±200	Case-to-nozzle joint
B06T7052A	0	1950	±200	Exit cone
B06T7053A	120	1950	±200	Exit cone
B06T7054A	240	1950	±200	Exit cone
B06T7085A	184.5	486.4	-4 to +158	Igniter
B06T7086A	355.5	486.4	-4 to +158	Igniter

Table 4.10-3 GEI List--360L007B (RH)

Instrument No.	Location (deg)	Station	Range (°F)	Case Location
B06T8003A	270	534.5	±200	Forward segment
B06T8004A	135	694.5	±200	Forward segment
B06T8005A	45	694.5	±200	Forward segment
B06T8006A	215	694.5	±200	Forward segment
B06T8007A	270	694.5	±200	Forward segment
B06T8008A	325	694.5	±200	Forward segment
B06T8009A	90	778.98	±200	Forward segment (systems tunnel)
B06T8010A	135	931.48	±200	Forward center segment
B06T8011A	45	931.48	±200	Forward center segment
B06T8012A	215	931.48	±200	Forward center segment
B06T8013A	270	931.48	±200	Forward center segment
B06T8014A	325	931.48	±200	Forward center segment
B06T8015A	135	1091.48	±200	Forward center segment
B06T8016A	45	1091.48	±200	Forward center segment
B06T8017A	215	1091.48	±200	Forward center segment
B06T8018A	270	1091.48	±200	Forward center segment
B06T8019A	325	1091.48	±200	Forward center segment
B06T8020A	90	1258.98	±200	Aft center segment (systems tunnel)
B06T8021A	135	1411.48	±200	Aft center segment
B06T8022A	45	1411.48	±200	Aft center segment
B06T8023A	215	1411.48	±200	Aft center segment
B06T8024A	270	1411.48	±200	Aft center segment
B06T8025A	325	1411.48	±200	Aft center segment
B06T8026A	320	1511	±200	ET attach ring
B06T8027A	266	1511	±200	ET attach ring
B06T8028A	220	1511	±200	ET attach ring
B06T8029A	135	1535	±200	Aft segment
B06T8030A	45	1535	±200	Aft segment
B06T8031A	90	1565	±200	Aft segment (systems tunnel)
B06T8032A	150	1701.86	±200	Aft segment
B06T8033A	30	1701.86	±200	Aft segment
B06T8034A	270	1701.86	±200	Aft segment
B06T8035A	135	1701.86	±200	Aft segment
B06T8036A	45	1751.5	±200	Aft segment
B06T8037A	215	1751.5	±200	Aft segment
B06T8038A	270	1751.5	±200	Aft segment
B06T8039A	325	1751.5	±200	Aft segment
B06T8040A	150	1821	±200	Aft segment
B06T8041A	30	1821	±200	Aft segment
B06T8042A	270	1821	±200	Aft segment
B06T8043A	180	1847	±200	Flex bearing
B06T8044A	180	1845	±200	Nozzle throat
B06T8045A	60	1847	±200	Flex bearing
B06T8046A	60	1845	±200	Nozzle throat
B06T8047A	300	1847	±200	Flex bearing
B06T8048A	300	1845	±200	Nozzle throat

Table 4.10-3 GEI List--360L007B (RH) (Cont)

Instrument No.	Location (deg)	Station	Range (°F)	Case Location
B06T8049A	180	1876.6	±200	Case-to-nozzle joint
B06T8050A	60	1876.6	±200	Case-to-nozzle joint
B06T8051A	300	1876.6	±200	Case-to-nozzle joint
B06T8052A	180	1950	±200	Exit cone
B06T8053A	60	1950	±200	Exit cone
B06T8054A	300	1950	±200	Exit cone
B06T8085A	355.5	486.4	-4 to +158	Igniter
B06T8086A	184.5	486.4	-4 to +158	Igniter

Table 4.10-4. 75 Percent Calibration Results

LH Motor		RH Motor	
Gage	Reading (psia)	Gage	Reading (psia)
B47P1300C	765.8	B47P2300C	765.8
B47P1301C	765.8	B47P2301C	769.8
B47P1302C	767.8	B47P2302C	765.8

Table 4.10-5. Field Joint Heater Temperature Sensors

Instrument No.	Location (deg)	Station	Range (°F)	Required Accuracy (%)	Digital*	Remarks
			LH SRM Heater Temperature Sensor List			
B06T7060	15	851.5	-4 to +158	±1	1	Forward heater
B06T7061	135	851.5	-4 to +158	±1	1	Forward heater
B06T7062	195	851.5	-4 to +158	±1	1	Forward heater
B06T7063	285	851.5	-4 to +158	±1	1	Forward heater
B06T7064	15	117.15	-4 to +158	±1	1	Center heater
B06T7065	135	1171.5	-4 to +158	±1	1	Center heater
B06T7066	195	1171.5	-4 to +158	±1	1	Center heater
B06T7067	285	1171.5	-4 to +158	±1	1	Center heater
B06T7068	15	1491.5	-4 to +158	±1	1	Aft heater
B06T7069	135	1491.5	-4 to +158	±1	1	Aft heater
B06T7070	195	1491.5	-4 to +158	±1	1	Aft heater
B06T7071	285	1491.5	-4 to +158	±1	1	Aft heater
			RH SRM Heater Temperature Sensor List			
B06T8060	15	851.5	-4 to +158	±1	1	Forward heater
B06T8061	135	851.5	-4 to +158	±1	1	Forward heater
B06T8062	195	851.5	-4 to +158	±1	1	Forward heater
B06T8063	285	851.5	-4 to +158	±1	1	Forward heater
B06T8064	15	1171.5	-4 to +158	±1	1	Center heater
B06T8065	135	1171.5	-4 to +158	±1	1	Center heater
B06T8066	195	1171.5	-4 to +158	±1	1	Center heater
B06T8067	285	1171.5	-4 to +158	±1	1	Center heater
B06T8068	15	1491.5	-4 to +158	±1	1	Aft heater
B06T8069	135	1491.5	-4 to +158	±1	1	Aft heater
B06T8070	195	1491.5	-4 to +158	±1	1	Aft heater
B06T8071	285	1491.5	-4 to +158	±1	1	Aft heater

*Sampling rate given in samples per minute (SPM)

90407-7.3

Table 4.10-6. S&A Arm and Safe Delta Times

SRB IGNITION S&A ROTATION - STS-33R
(B47SA0.070 - IGNITION S&A FUNCTIONAL TEST)

RATE #	GMT	COMMAND	GMT	RESPONSE	DELTA	LEFT	RIGHT	LEFT	RIGHT
	50936.608	B55K3000X1-LH ARM	50939.235	B55X1842X1-LH ARM	2.627	2.627			
1	50936.848	B55K4000X1-RH ARM	50937.755	B55X2842X1-RH ARM	0.907		0.907		
	50945.688	B55K3002X1-LH SAFE	50946.436	B55X1843X1-LH SAFE	0.748			0.748	
	50945.968	B55K4002X1-RH SAFE	50946.755	B55X2843X1-RH SAFE	0.787				0.787
	61349.368	B55K3000X1-LH ARM	61350.436	B55X1842X1-LH ARM	1.068	1.068			
2	61349.608	B55K4000X1-RH ARM	61350.555	B55X2842X1-RH ARM	0.947		0.947		
	61357.008	B55K3002X1-LH SAFE	61357.835	B55X1843X1-LH SAFE	0.827			0.827	
	61357.248	B55K4002X1-RH SAFE	61357.955	B55X2843X1-RH SAFE	0.707				0.707
	61500.048	B55K3000X1-LH ARM	61500.835	B55X1842X1-LH ARM	0.787	0.787			
3	61500.288	B55K4000X1-RH ARM	61501.155	B55X2842X1-RH ARM	0.867		0.867		
	61507.608	B55K3002X1-LH SAFE	61508.436	B55X1843X1-LH SAFE	0.828			0.828	
	61507.888	B55K4002X1-RH SAFE	61508.755	B55X2843X1-RH SAFE	0.867				0.867
	61547.048	B55K3000X1-LH ARM	61547.835	B55X1842X1-LH ARM	0.787	0.787			
4	61547.328	B55K4000X1-RH ARM	61548.155	B55X2842X1-RH ARM	0.827		0.827		
	61554.728	B55K3002X1-LH SAFE	61555.436	B55X1843X1-LH SAFE	0.708			0.708	
	61554.969	B55K4002X1-RH SAFE	61555.755	B55X2843X1-RH SAFE	0.786				0.786
	61638.728	B55K3000X1-LH ARM	61639.635	B55X1842X1-LH ARM	0.907	0.907			
5	61638.968	B55K4000X1-RH ARM	61639.755	B55X2842X1-RH ARM	0.787		0.787		
	61646.328	B55K3002X1-LH SAFE	61647.035	B55X1843X1-LH SAFE	0.707			0.707	
	61646.568	B55K4002X1-RH SAFE	61647.355	B55X2843X1-RH SAFE	0.787				0.787
	61736.768	B55K3000X1-LH ARM	61737.635	B55X1842X1-LH ARM	0.867	0.867			
6	61737.008	B55K4000X1-RH ARM	61737.755	B55X2842X1-RH ARM	0.747		0.747		
	61744.288	B55K3002X1-LH SAFE	61745.035	B55X1843X1-LH SAFE	0.747			0.747	
	61744.528	B55K4002X1-RH SAFE	61745.355	B55X2843X1-RH SAFE	0.827				0.827
	61832.768	B55K3000X1-LH ARM	61833.635	B55X1842X1-LH ARM	0.867	0.867			
7	61833.008	B55K4000X1-RH ARM	61833.755	B55X2842X1-RH ARM	0.747		0.747		
	61840.288	B55K3002X1-LH SAFE	61841.035	B55X1843X1-LH SAFE	0.747			0.747	
	61840.568	B55K4002X1-RH SAFE	61841.356	B55X2843X1-RH SAFE	0.788				0.788
	61917.928	B55K3000X1-LH ARM	61918.835	B55X1842X1-LH ARM	0.907	0.907			
8	61918.168	B55K4000X1-RH ARM	61918.956	B55X2842X1-RH ARM	0.788		0.788		
	61925.528	B55K3002X1-LH SAFE	61926.235	B55X1843X1-LH SAFE	0.707			0.707	
	61925.768	B55K4002X1-RH SAFE	61926.555	B55X2843X1-RH SAFE	0.787				0.787
	61955.768	B55K3000X1-LH ARM	61956.636	B55X1842X1-LH ARM	0.868	0.868			
9	61956.008	B55K4000X1-RH ARM	61956.756	B55X2842X1-RH ARM	0.748		0.748		
	62003.288	B55K3002X1-LH SAFE	62004.035	B55X1843X1-LH SAFE	0.747			0.747	
	62003.528	B55K4002X1-RH SAFE	62004.356	B55X2843X1-RH SAFE	0.828				0.828
	62035.088	B55K3000X1-LH ARM	62035.835	B55X1842X1-LH ARM	0.747	0.747			
10	62035.328	B55K4000X1-RH ARM	62036.155	B55X2842X1-RH ARM	0.827		0.827		
	62042.888	B55K3002X1-LH SAFE	62043.635	B55X1843X1-LH SAFE	0.747			0.747	
	62043.128	B55K4002X1-RH SAFE	62043.956	B55X2843X1-RH SAFE	0.828				0.828
	62453.448	B55K3000X1-LH ARM	62454.235	B55X1842X1-LH ARM	0.787	0.787			
11	62453.688	B55K4000X1-RH ARM	62454.555	B55X2842X1-RH ARM	0.867		0.867		
	62501.168	B55K3002X1-LH SAFE	62502.035	B55X1843X1-LH SAFE	0.867			0.867	
	62501.409	B55K4002X1-RH SAFE	62502.155	B55X2843X1-RH SAFE	0.746				0.746
	62540.848	B55K3000X1-LH ARM	62541.635	B55X1842X1-LH ARM	0.787	0.787			
12	62541.088	B55K4000X1-RH ARM	62541.956	B55X2842X1-RH ARM	0.868		0.868		
	62548.368	B55K3002X1-LH SAFE	62549.235	B55X1843X1-LH SAFE	0.867			0.867	
	62548.609	B55K4002X1-RH SAFE	62549.355	B55X2843X1-RH SAFE	0.746				0.746
	62626.168	B55K3000X1-LH ARM	62627.035	B55X1842X1-LH ARM	0.867	0.867			
13	62626.448	B55K4000X1-RH ARM	62627.155	B55X2842X1-RH ARM	0.707		0.707		
	62633.728	B55K3002X1-LH SAFE	62634.436	B55X1843X1-LH SAFE	0.708			0.708	
	62633.968	B55K4002X1-RH SAFE	62634.755	B55X2843X1-RH SAFE	0.787				0.787
					AVERAGE :	0.990	0.810	0.766	0.790

E: THE IGN. S&A WAS ROTATED 13 TIMES AS PART OF IPR 33RV-0165.

Table 4.10-7. S&A Activity Times for 360L007 (STS-33R) at T-5 Minutes

Rotation Times*
(arm command to arm indication)

LH motor	1.085 sec
RH motor	0.965 sec

*The data sample rate is five times per second; therefore, the actual rotation times could be ±0.200 sec sooner. The command times are as indicated

4.11.1.2 External Insulation

Factory Joint Weatherseals. Two of the 14 factory joint weatherseals were unbonded. The LH aft segment stiffener-to-stiffener factory joint weatherseal was unbonded on the aft edge over approximately 70 percent of the circumference. The depth of the unbond measured from 0.8 to 0.9 in., which was to the pin retainer band. The unbond exhibited failure between the Chemlok® 205 and the case. There was no evidence of soot or heat effects on the unbonds. Paint was peeled from the case and attached to the edge of the weatherseal intermittently along the unbond. Corrosion was evident on the case under the peeled paint and under the unbonded weatherseal. A forward edge unbond was also noted near 310 deg; it measured 0.5 in. longitudinally by about 0.75 in. circumferentially.

Two insulation-to-case unbonds were identified on the forward edge of the RH forward segment cylinder-to-cylinder weatherseal. The weatherseal was unbonded at 160 deg for 14 in. to a depth ranging from 1.0 to 1.5 in. and at 135 deg for 11 in. to a depth of 0.1 inch. An aft edge unbond was noted at 210 deg and measured 0.6 in. longitudinally by about 1.0 in. circumferentially. All unbonds were at the Chemlok® 205-to-case interface.

All other factory joint weatherseals were in excellent condition. Normal small debris impact damage from reentry was evident intermittently on the aft edges of the weatherseals. Normal heat effects and discoloration were evident on the weatherseals of both aft segments. No significant areas of missing ethylene-propylene-diene monomer (EPDM) insulation were noted. The K5NA closeouts over the thermocouple wires were in good condition, with no indications of leaking water.

Stiffener Stubs and Rings. The insulation over the stiffener stubs and rings was in good condition. Normal heat effects and discoloration were evident on all surfaces in the 220- to 320-deg region. There were no significant areas of missing material. The EPDM was well bonded to the stiffener stubs and appeared to be well bonded to the stiffener rings. There was very little stiffener ring damage due to the high sea state at splashdown. The K5NA repair on the outboard edge of the forward stiffener stubs showed normal erosion and some small missing chunks intermittently around the circumference.

4.11.1.3 Case-to-Nozzle Joints. Based on the visual evaluation, both case-to-nozzle joints performed well. No gas paths through the polysulfide adhesive were identified.

The disassembled joints showed the failure mode was 83 percent cohesive at disassembly in the LH polysulfide bondline, while the RH motor failed 89 percent cohesive. One small void was identified in the polysulfide adhesive at 109 deg on the LH case-to-nozzle joint, measuring 1.6 in. longitudinally by 0.25 in. wide. The void extended across the step but did not reach the wiper O-ring and was not penetrated by hot gas. Porosity was evident on both joints in the step region. The polysulfide vent slot fill on these motors was 32 percent and 84 percent for the LH and RH motors, respectively.

4.11.1.4 Field Joints. The internal insulation in all six field joints performed as designed, and no anomalous conditions were noted. J-leg tip contact was evident and the full circumference at each joint. Wet soot deposits extending down the bondline were noted on all of the field joints, generally to a depth of 0.2 to 0.7 in. radially into the bondline (outboard from the remaining material). The maximum depth of the wet soot was 1.35 in. on the RH center field joint. No heat effects were evident under the soot. Similar wet sooting has been noted on previous RSRM joints and is believed to occur at reentry or splashdown during joint flexing.

There were no clevis edge separations that were recordable (over 0.10 in. deep). Some tang edge separations were visible on the field joints, which will be evaluated further when the segments reach the Clearfield H-7 facility.

Clevis insulation cracks were noted on the radius region insulation on four out of six field joints. Some cracks were noted on prefire problem reports. The cracks did not have any effect on the function of the joint. Cracks and crazing will be further evaluated when the segments reach the Clearfield H-7 facility.

4.11.1.5 Ignition System Insulation. The igniter chamber insulation, as well as the igniter-to-case joint insulation for both igniter joints, showed normal erosion. One blowhole through the putty of the LH igniter adapter-to-case joint was present at 332 deg. The putty in the RH joint had no blowhole, and putty was extruded up to and on the adapter intermittently around the circumference. The igniter adapter-to-igniter chamber joint on the RH motor had a blowhole through the putty at 340 deg. Soot was in the putty from 315 to 350 deg but did not extend to the gasket. No adverse effects on joint performance resulted from either blowhole.

4.11.1.6 Internal Acreage Insulation. The acreage insulation, including the internal insulation over each of the factory joints, appeared in good condition. No evidence of hot gas penetration through the insulation was identified.

Forward Segments. The stress relief flap was present full circumference on both forward segments but was heat affected and eroded. The castable inhibitors were completely missing over the full circumference. The flaps had a scalloped appearance similar to that seen on previous RSRM flight forward segment flaps. The acreage insulation was in normal condition. The 11-point star pattern was easily distinguishable in the liner.

Both forward domes near the igniter boss were extensively inspected for excessive erosion and thin insulation. No gas paths or areas of abnormal erosion were identified. Preliminary insulation thickness measurements indicated adequate thermal SFs near the igniter boss. The insulation in this area was also removed, and no indication of folds or voids at the insulation-to-case interface were noted.

A final evaluation of the thermal performance of the insulation will be accomplished after internal thicknesses are measured at the Clearfield H-7 facility.

Center Segments. Only two inhibitor tears greater than 3 in. radially were noted in either aft center segment inhibitor stub. Both were noted on the RH aft center segment and measured 4.0 and 4.5 in. in length.

Some radial tears were noted in the forward center segment nitrile butadiene rubber (NBR) inhibitor stubs (nine on the LH motor and eight on the RH motor). The tears in the forward center segments ranged from 5.0 to 11.75 in. radially. The radial extent and frequency of the tears identified in the inhibitor stubs are within the range of tears noted on past flight motors. The edges of the tears demonstrated no material loss or erosion, indicating that the tears occurred after motor burn.

The flap and acreage insulation exhibited normal erosion. The castable inhibitor was completely missing on all four center segments. The flap and capture feature/EPDM was completely eroded to the flap bulb on the aft center segments and partially eroded on the forward center segments.

Aft Segments. Four to six small blisters were identified on the capture feature/ EPDM in the LH aft dome. The largest blister measured 1.75 in. axially by 0.25 in.

circumferentially. This was significantly less than was seen on the previous flight set and is considered a normal condition.

The aft segment NBR inhibitor stubs exhibited scalloped erosion around the circumference. These areas had a very short inhibitor stub with intermittent inhibitor pieces taller than adjacent areas. This condition has been noted on all previous flight RSRM aft segments. This uneven erosion was not typically seen to this extent on HPM motors, but it does not appear to be a problem. There were no tears in either inhibitor. The aft segment acreage insulation was in normal condition. There were no gouges, separations, cuts, missing material, excessive erosion, or other areas of blisters.

4.11.2 Case Component Performance

4.11.2.1 Summary. Evaluation of the steel case indicated the hardware performed as expected during flight. Complete case evaluation results are in Volume II of this report.

4.11.2.2 Stiffener Stubs, Stiffener Rings, and ET Attach Stubs. The stiffener rings and case stubs had no apparent water impact damage. No cracks or warpage was found. No deformed boltholes were observed. No web cracks were noted and no bolts were missing or elongated.

Based on missing Instafoam, the cavity collapse load centerlines for the RH and LH motors were estimated to be at 340 and 100 deg, respectively.

4.11.2.3 Field Joints. The case field joint surface conditions were as expected. Fretting ranged from none on one joint to locally medium on two joints. The RH center field joint had no fretting. The LH center and RH forward joints had the worst. Figure 4.11-1 provides a subjective summary of the fretting.

4.11.2.4 Case-to-Nozzle Joint. The case-to-nozzle joint on both motors was in excellent condition. There were no signs of metal damage to any of the sealing surfaces or boltholes, and there was no heat-affected metal, corrosion, or damaged bolts.

4.11.2.5 Igniter-to-Forward Dome Joint. The igniter-to-forward dome joint on both motors was in excellent condition. There were no signs of metal damage to any sealing surface or boltholes, and there was no heat-affected metal, corrosion, or damaged bolts.

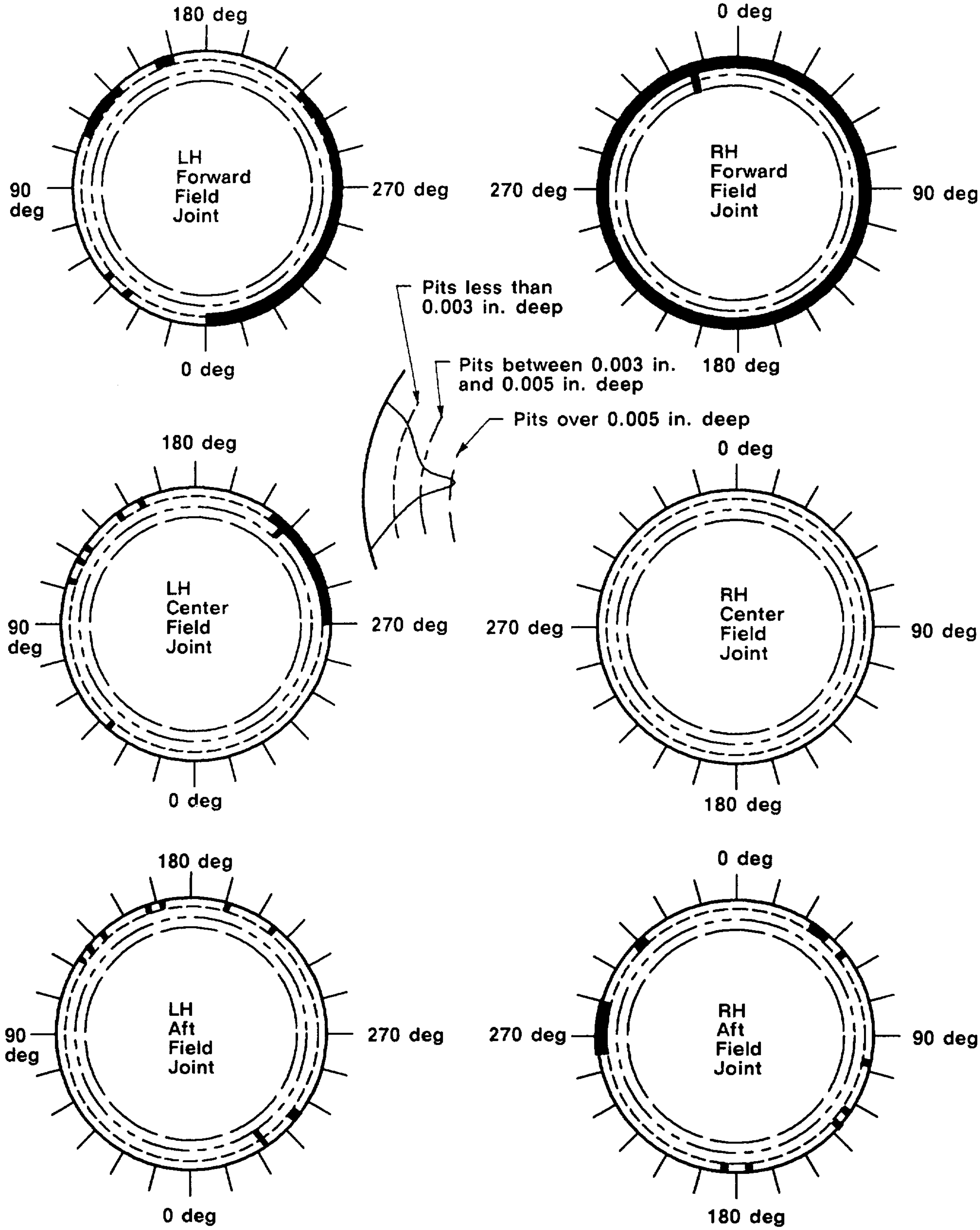

Figure 4.11-1. Sketch of Overall Field Joint Fretting Observations

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4.11.2.6 Factory Joint External Surfaces. Light corrosion was found at the weatherseal unbond location on the RH forward cylinder-to-cylinder joint. Medium to heavy corrosion was observed under the unbonded weatherseal on the LH aft stiffener-to-stiffener joint. Light corrosion was also seen on the RH forward dome-to-cylinder joint. No corrosion was seen on any other joints.

4.11.2.7 Miscellaneous Case Surfaces. All cork, K5NA, cables, and gauges associated with the GEI were removed at Hangar AF because of corrosion pits observed on previous case segments from an instrumentation spot band. These spot bands are for lightning protection and use silver-filled epoxy (Eccobond 56C). The instrumentation is then covered with K5NA and Hypalon paint. During SRB reentry, the Hypalon paint blisters, allowing sea water to soak into the K5NA, producing a galvanic cell between the case and the silver-filled epoxy. The case surfaces under the removed GEI runs had light corrosion. No pits were observed at any GEI spot bond location.

4.11.2.8 OPTs, Special Bolts, and Special Bolt Plugs. Soot deposits were observed on the threads on the tip of the OPTs and up to the primary seals. The physical condition of the OPTs was excellent.

All LH and RH igniter special bolts experienced typical light sooting up to the primary O-ring and on the ends of the special bolts.

4.11.2.9 Vent Port and Leak Check Port Plugs. The metal surfaces of the plugs were free of soot, debris, and corrosion.

4.11.2.10 Joint Heaters. Both RH and LH igniter heaters were evaluated before and after removal. No discoloration or warping was noted, indicating proper installation and nominal performance.

4.11.3 Seals Performance

4.11.3.1 Summary. Evaluation of the field joints indicated the internal seals performed as expected during flight. All internal seals, including the redesigned field joint seals and case-to-nozzle joint seals, appeared to have performed well, with no hot gas leakage evident. A complete evaluation is in Volume II of this report.

4.11.3.2 Exit Cone Field Joint. The assessment team was not notified of exit cone disassembly, so the in-groove inspection of the O-rings and joint area was not done. The LH primary O-ring was damaged at about 0 deg with 30 in. of O-ring missing. At splashdown, the glass-cloth phenolic (GCP) delaminated in the primary O-ring groove from 292 through 0 to 4 deg, probably causing the O-ring damage. The metal surfaces of both aft exit cones had intermittent medium corrosion on the outer edge of the forward face and between the O-ring grooves. The RH aft exit cone had a concentration of medium corrosion between 115 and 155 deg.

4.11.3.3 Case Field Joints. Inspection of the field joint seals revealed no anomalous conditions. All motor pressure was contained by the insulation J-joint. There was no corrosion or damage found on any of the O-ring sealing surfaces. The V_2 filler was also found to be in excellent condition. None of the vent ports were obstructed by the V_2 filler. The grease application was nominal.

4.11.3.4 OPT, Special Bolts, and Special Bolt Plug Seals. There was no evidence of gas leakage past the primary seals on any of the OPTs. The LH and RH primary seals saw pressure but there was no soot observed on them. Soot deposits were observed on the tips of the transducer threads and up to the primary seals. All of the seals performed nominally.

Special bolt primary seals were in excellent condition and performed as expected. Special bolt plug seals were also in excellent condition. All LH and RH igniter special bolts experienced typical light soot up to the primary O-ring and on the end of the special bolts.

4.11.3.5 Ignition System Joint. The igniter removal on this flight set was performed using dynamometers and guide pins in order to monitor the loads involved and minimize the putty disturbance during disassembly.

The seals of the S&A, igniter outer, and igniter inner gaskets revealed no erosion or heat effect.

The LH igniter outer putty had a blowhole in the outer putty at 332 deg. Soot was observed on the entire circumference of the inner edge of the outer gasket. Soot to the primary seal was observed on the forward face from 330 to 0 deg. Soot to the primary seal was also observed on the aft face from 270 to 279 deg. No soot was observed past the primary seal on either face. Two very small dimples (less than 0.003 in. in diameter) were observed on the forward face. One was on the primary seal at 235 deg and the other was on the secondary seal at 144 deg. Also, traces of touchup paint were seen on the environmental seal outer edge.

The LH inner gasket had soot on the outside edge of the aft gasket face from 210 through 0 to 130 deg. Soot did not reach the outer seal. No soot was observed on the forward face. Putty was observed on the inner edge from 20 to 65 deg. No putty was on the forward or aft gasket face.

The RH igniter outer putty had no blowhole. Putty was on the outer gasket inner edge from 18 to 101 and from 207 to 270 deg. No putty was observed on either forward or aft gasket face.

The RH inner putty had a terminated blowhole at 340 deg. No soot reached the inner gasket. A small depression was observed on the outer seal aft face crown at 10 deg. It was approximately 0.002 in. deep by 0.004 in. wide. Detailed inspection verified that the flaw was within the acceptance criteria of 0.002 in. deep by 0.005 in. wide. Putty was on the outside gasket diameter intermittently around the entire circumference.

The LH and RH igniter inner joint packing with retainers (Stat-O-Seals®) were in good condition. None had any apparent damage.

4.11.3.6 Case-to-Nozzle Joint. The overall joint condition was excellent on both motors. Motor pressure was halted at the polysulfide adhesive, leaving the fluorocarbon O-rings untouched. No obvious disassembly damage was noted on the O-rings.

The grease on the RH fixed housing sealing surface was light to nonexistent. Three radial bolthole plugs were damaged on disassembly.

The LH and RH case-to-nozzle joint Stat-O-Seals were in good condition, with no disassembly damage.

4.11.3.7 Vent Port Plugs. The case field joint and case-to-nozzle joint vent port plugs and seals on each motor were in excellent condition. The vent port plug O-rings showed no evidence of heat effects. The fluorocarbon O-rings, glands, and metal surfaces of the plugs were free of soot, debris, and corrosion.

4.11.3.8 Leak Check Port Plugs. The leak check port plugs and seals on the LH and RH motors in the case field joints, case-to-nozzle joints, aft exit cone joints, and the ignition system joints were in good condition. None of the leak check port plug O-rings showed any evidence of heat effects. The fluorocarbon O-rings, glands, and metal surfaces of the plugs were free of soot, debris, and corrosion.

4.11.3.9 Internal Nozzle Seals

Forward End Ring-to-Nose Inlet Housing Joint. Inspection of the joint did not reveal any obvious pressure paths through the RTV/adhesive of the joint interface. Scallop-shaped sooting of the grease was observed around the full circumference of the joint about halfway between the edge of the aluminum housing and the primary O-ring groove situated between boltholes. Heavy sooting was observed at 96 through 138 and 228 through 318 deg on the LH motor and 334 through 0 through 18 and 120 through 150 deg on the RH motor. No soot or blowby was observed up to or past the primary O-ring on the LH motor, but light soot was seen on the RH motor to the primary O-ring at 126 through 162 and 198 through 258 deg. No soot or evidence of blowby was observed past the primary on the RH motor. No apparent damage to the primary or secondary O-rings was found during preliminary inspection, and the sealing surfaces showed no assembly or disassembly damage. Typical light corrosion was observed intermittently on the secondary O-ring sealing surface of the RH motor.

Nose Inlet Housing-to-Throat Support Housing. A pressure path through the RTV at 140 deg was noted on the LH motor. No soot or evidence of blowby was present past the primary O-ring. A terminated void in the RTV was noted at 100 deg on the RH motor. No soot or evidence of blowby was present up to or past the primary O-ring. No apparent damage was found during preliminary inspection of the primary or secondary O-rings. Inspection of the sealing surfaces revealed no signs of damage. Typical light corrosion was found intermittently on the nose inlet housing at the adhesive-to-metal interface at 90 through 140 deg on the LH motor and 95 through 105 and 228 through 318 deg on the RH motor.

Forward Exit Cone-to-Throat Support Housing. Inspection of the joint revealed no pressure paths through the RTV backfill. No apparent damage to the primary or secondary O-rings was found during preliminary inspection and the sealing surfaces showed no assembly/disassembly damage. No corrosion was found on any of the joint sealing surfaces. Typical light corrosion was found on the bevel of the throat of the RH motor from 2.5 to 5 deg. This corrosion coincides with the bondline separations on the forward exit cone.

Fixed Housing-to-Aft End Ring Joint. Inspection of the joint revealed no pressure paths through the RTV. The RTV was observed up to the land forward of the primary O-ring at 40 through 127.5 deg on the LH motor. RTV was observed up to the primary O-ring at 103 through 133, 145 through 165, and 245 through 310 deg on the RH motor. No damage was found during preliminary inspection of the primary and secondary O-rings and the sealing surfaces showed no signs of damage. Typical light corrosion was observed on the inside diameter lip of the aft end ring.

4.11.4 Nozzle Performance

4.11.4.1 Summary. Postflight evaluation indicated both nozzles performed as expected during flight. Phenolic erosion was smooth and normal. Complete evaluation is in Volume V of this report.

4.11.4.2 360L007A (LH) Nozzle

Aft Exit Cone. The aft exit cone was severed by the LSC during parachute descent. The radial cut through the GCP appeared nominal, with no anomalies observed. Some carbon-cloth phenolic (CCP) liner was missing and portions of the GCP insulator were torn and delaminated. These are typical postflight phenomena that occur during exit cone severance and at splashdown. The exposed GCP plies showed no signs of heat effect.

The only observation outside the RSRM nozzle experience was the thermal curtain retainer screw helical coil inserts on the compliance ring. Thirty-six of the 192 required on the nozzle were pulled out above the outside diameter (OD) surface of the compliance ring.

The actuator brackets showed only minor paint scratches, scrapes, and chips due to actuator removal. The primer remained intact and no metal damage or loose bolts were observed.

Four separations were observed between the polysulfide and the aft exit cone shell. Postflight measurements of the polysulfide groove radial width showed that the GCP insulator did not pull away from the aluminum shell during cooldown.

The RTV backfill was below the joint charline on the nozzle 360 deg circumferentially. No voids were noted. RTV reached the primary O-ring for 70 percent of the joint circumference.

Forward Exit Cone Assembly. The CCP liner was intact from 110 to 345 deg, with smooth erosion for the forward 11 inches. Moving aft, the next 17 in. had missing

CCP, but no heat effect to the GCP. The aft 6 in. had CCP intact with typical dimpled erosion approximately 0.1 in. deep radially.

Throat Assembly. The throat assembly had smooth erosion on the throat inlet and the forward 9 in. of the throat ring, with typical rippled erosion on the aft 7 inches. Typical inlet ring forward edge postburn CCP wedgeouts were found intermittently around the circumference, measuring 0.70 in. axially by 1.0 in. radially.

Nose Inlet Assembly. The -503 ring had smooth erosion and a large number of impact marks, typically 0.2 to 0.3 in. in diameter and 0.05 to 0.1 in. deep. Some marks had slag in them. The -504 ring had smooth erosion, no impact marks and no wedgeouts or pop-ups.

The nose cap had smooth erosion with minor wash areas on the forward 12 in. (0.05 in. deep radially). Slag deposits were noted on the forward 18 in. from 90 to 270 deg. Typical postburn impact marks on the forward end (some with slag deposits) were noted intermittently around the circumference. Typical postburn wedgeouts of charred CCP were found on the aft 2 in. intermittently around the circumference.

Cowl Ring. The cowl ring showed typical ridged erosion (0.06 in. deep). This is due to the low ply angle. Postburn wedgeouts of charred CCP were observed on the aft 2.5 in. from 18 to 260 deg, measuring 1.0 in. deep radially.

Outer Boot Ring (OBR). The OBR had postburn wedgeouts on the forward 1.5 in. of the ring from 105 to 118 and from 239 to 265 deg. They were 0.7 in. deep radially. The same area showed popped up, charred CCP plies intermittently around the circumference. There were typical postburn delaminations in the aft end along the 0 deg ply wraps. These were 0.6 to 1.9 in. deep axially. The aft tip adjacent to the flex boot was typically fractured and wedged out.

Fixed Housing Assembly. The fixed housing insulation erosion was smooth and uniform. The forward 2 in. of the fixed housing showed typical postburn wedgeouts of charred CCP intermittently around the circumference with some slag deposits on exposed plies. The maximum radial depth of the wedgeouts was 1.5 inches.

4.11.4.3 360L007B (RH) Nozzle

Aft Exit Cone. The aft exit cone was severed by the LSC during parachute descent. The radial cut through the GCP appeared nominal, with no anomalies observed.

All of the CCP liner was missing and portions of the GCP insulator were torn and delaminated. These are typical postflight phenomena that occur during exit cone severance and at splashdown. The exposed GCP plies showed no signs of heat effect.

The only observation outside the RSRM nozzle experience was the thermal curtain retainer screw helical coil inserts on the compliance ring. Eighty-one of the 192 required were pulled out above the OD surface of the compliance ring.

The actuator brackets showed only minor paint scratches, scrapes, and chips due to actuator removal. The primer remained intact and no metal damage or loose bolts were observed.

Two separations were observed between the polysulfide and the aft exit cone shell. Postflight measurements of the polysulfide groove radial width showed that the GCP insulator did not pull away from the aluminum shell during cooldown.

The RTV backfill was below the joint charline on the nozzle 360 deg circumferentially. No voids were noted. RTV reached the primary O-ring for 95 percent of the circumference.

Forward Exit Cone Assembly. The CCP liner was intact, with smooth erosion for the forward 10 in. and with one 0.75-in.-wide axial wedgeout at the forward end from 300 to 330 deg. Moving aft, the next 13 in. had missing CCP, but no heat effect to the GCP. The aft 12 in. had CCP intact with typical dimpled erosion approximately 0.1 in. deep radially.

Throat Assembly. The throat assembly had smooth erosion on the throat inlet and the forward 10 in. of the throat, with typical rippled erosion on the aft 6 in. of the throat ring. There were two erosion wash areas found on the aft 6 in. of the throat ring at 200 and 300 deg measuring approximately 3 in. circumferentially by 6 in. axially by 0.16 in. radially. There were no wedgeouts or pop-ups.

Nose Inlet Assembly. The -503 ring had smooth erosion and intermittent minor impact marks, typically 0.3 in. in diameter and 0.05 in. deep. The -504 ring had smooth erosion, no impact marks, and no wedgeouts or pop-ups.

The nose cap had smooth erosion with minor wash areas on the forward 8 in. (0.05 in. deep radially). Slag deposits were noted on the forward 18 in. from 270 through 0 to 90 deg. Typical postburn impact marks on the forward end (some with slag deposits) were noted intermittently around the circumference. Typical postburn wedgeouts of charred CCP were found on the aft 2 in. intermittently around the circumference.

Cowl Ring. The cowl ring showed typical ridged erosion (0.1 in. deep) on the forward 5 inches. Wedgeouts were found on the aft 2.5 in. from 260 through 0 to 56 deg. They measured 1.0 in. deep radially.

Outer Boot Ring. The OBR had popped plies on the forward 1.3 in. from 4 to 10 deg. No wedgeouts were noted. Typical postburn delaminations were found in the aft end along the 0-deg ply wraps and were 0.5 in. deep. Ninety-four percent of the aft tip adjacent to the flex boot was typically fractured and wedged out.

Fixed Housing Assembly. The fixed housing insulation erosion was smooth and uniform. The forward 2 in. of the fixed housing showed typical postburn wedgeouts of charred CCP intermittently around the circumference, with some slag deposits on exposed plies. The maximum radial depth of the wedgeouts was 0.5 inches.

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